Rural-Urban Differences in Diabetes Care and Control in 42 Low- and Middle-Income Countries: A Cross-sectional Study of Nationally Representative Individual-Level Data

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OBJECTIVE

Diabetes prevalence is increasing rapidly in rural areas of low- and middle-income countries (LMICs), but there are limited data on the performance of health systems in delivering equitable and effective care to rural populations. We therefore assessed rural-urban differences in diabetes care and control in LMICs.

RESEARCH DESIGN AND METHODS

We pooled individual-level data from nationally representative health surveys in 42 countries. We used Poisson regression models to estimate age-adjusted differences in the proportion of individuals with diabetes in rural versus urban areas achieving performance measures for the diagnosis, treatment, and control of diabetes and associated cardiovascular risk factors. We examined differences across the pooled sample, by sex, and by country.

RESULTS

The pooled sample from 42 countries included 840,110 individuals (35,404 with diabetes). Compared with urban populations with diabetes, rural populations had ∼15–30% lower relative risk of achieving performance measures for diabetes diagnosis and treatment. Rural populations with diagnosed diabetes had a 14% (95% CI 5–22%) lower relative risk of glycemic control, 6% (95% CI −5 to 16%) lower relative risk of blood pressure control, and 23% (95% CI 2–39%) lower relative risk of cholesterol control. Rural women with diabetes had lower achievement of performance measures relating to control than urban women, whereas among men, differences were small.

CONCLUSIONS

Rural populations with diabetes experience substantial inequities in the achievement of diabetes performance measures in LMICs. Programs and policies aiming to strengthen global diabetes care must consider the unique challenges experienced by rural populations.

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Approximately 80% of the 537 million people with diabetes worldwide live in low- and middle-income countries (LMICs) (1). The rising global prevalence of diabetes is commonly associated with changing dietary, work, and physical activity patterns as countries become more urbanized (2,3). However, individuals living in rural areas have not been spared from this growing diabetes risk. One of every three individuals with diabetes worldwide lives in a rural area (152.6 million total rural individuals with diabetes) (1). Although diabetes prevalence is increasing in rural areas of both LMICs and high-income countries, relative growth has been faster in rural areas of LMICs than in rural areas of high-income countries (4).

In response to the rising rural diabetes burden, health systems in LMICs are increasingly tasked with scaling up primary health care services for diabetes in rural areas. Globally, rural populations are often underserved by health systems as a result of challenges including geographic isolation, health worker shortage, and lower health spending than in urban areas (5,6). In a 2015 landmark report, the United Nations International Labor Organization found that a lack of granular nationally comparable evidence on rural health inequities has impeded policymakers in allocating resources to strengthen rural health systems (6). In the case of diabetes, prior research has demonstrated suboptimal delivery of evidence-based care in LMICs (7–12), but there are scarce data on how health systems in LMICs perform in delivering diabetes care in rural areas.

Evidence on rural-urban inequities in diabetes care and control in LMICs is urgently needed. In April 2021, the World Health Organization (WHO) launched the Global Diabetes Compact, a high-profile effort to strengthen diabetes health services with a focus on primary care management in LMICs. The Global Diabetes Compact aims to set population-based diabetes targets for 2030, stimulate investment in diabetes care, and monitor progress toward targets at the national, regional, and global levels (13,14). Of particular interest in the Global Diabetes Compact are demographic disparities that can inform the design of policies and programs to scale up diabetes care among those populations most left behind. As such, the current study aims to assess rural-urban differences in the diagnosis, treatment, and control of diabetes and associated cardiovascular risk factors in LMICs.

RESEARCH DESIGN AND METHODS

Data Sources

We conducted a cross-sectional analysis of pooled individual-level data from national health surveys conducted in 42 LMICs. Surveys were eligible for inclusion if they were completed in or after 2008, were nationally representative, were conducted in an LMIC as defined by the World Bank in the year the survey was conducted, had availability of individual-level data, contained data on rural versus urban residence, and included biologic measurements for diabetes.

Eligible surveys were identified using a two-step process. First, we searched for WHO Stepwise Approach to Surveillance (STEPS) surveys on the STEPS report website (15) and Non-Communicable Disease Microdata Repository (16). STEPS surveys were our preferred data source because they are recommended by the WHO to track progress toward Non-Communicable Disease targets at the population level (17,18). Second, for countries in which a STEPS survey was not available or had not been conducted, we performed a systematic search to identify additional surveys meeting eligibility criteria. Of the 42 surveys included, 33 were STEPS surveys and nine were non-STEPS surveys.

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Additional details on the search process, data sources, and measurement devices are reported in the Supplementary Material.

Sample and Definitions

The study sample consisted of respondents who were age 18–69 years, were not pregnant, and had an available biologic measurement for diabetes (point-of-care fasting capillary glucose, laboratory-based measurement of fasting plasma glucose, or glycated hemoglobin [HbA_{1c}]). We used this age criterion because it represented an overlapping age range of respondents in most underlying surveys.

We defined diabetes as use of a glucose-lowering drug (oral glucose-lowering medication or insulin) or an elevated biomarker meeting the WHO criteria for diabetes: fasting plasma glucose (FPG) $\geq$7.0 mmol/L (126 mg/dL), random plasma glucose $\geq$11.1 mmol/L (200 mg/dL), or HbA_{1c} $\geq$6.5% (19–21). In surveys reporting uncalibrated capillary glucose measurements, we converted values to plasma glucose by multiplying by a factor of 1.11 based on evidence that capillary values underestimate plasma values (22). This conversion is standard in large-scale population-based diabetes studies (7,23). Overall, 31 surveys reported using point-of-care capillary glucose, eight surveys reported FPG, and eight surveys reported HbA_{1c}. For individuals in five countries with both a glucose measurement and HbA_{1c} (China, Guyana, Iran, Mexico, and Romania), we used HbA_{1c} as our biomarker of interest in estimating the performance measures described below.

We adopted each survey's definition of rural or urban residence. A list of national definitions is reported in the Supplementary Material. In STEPS and other survey programs (24), these definitions are set by each country's national statistical office based on criteria such as administrative area, land use, infrastructure, and/or population size or density (25). Definitions therefore vary by country. It is not currently possible to generate harmonized classifications of urban and rural areas across countries (26). The United Nations Population Division recommends this approach because national statistical offices are most qualified to establish locally meaningful definitions of areas of residence (26).

Outcomes

Our outcomes were achievement of diabetes performance measures in three domains: diagnosis, treatment, and control of diabetes and associated cardiovascular risk factors. We adapted performance measures for these three domains from recommended population monitoring indicators and clinical guidance in the WHO Package of Essential Noncommunicable Disease Interventions for Primary Health Care (19). Our outcomes were generally consistent with proposed metrics in the WHO Global Diabetes Compact (13). Additional details on our definitions and their availability by survey are shown in the Supplementary Material.

In the diagnosis domain, ever tested was quantified among individuals with diabetes who ever had their blood glucose measured by a health worker. Awareness was quantified among individuals with diabetes who previously had been told by a health worker that they had raised blood glucose.

In the treatment domain, use of glucose-lowering medication was quantified among individuals in either of the following two groups: *1*) HbA_{1c} $\geq$8.0% (FBG $\geq$9.2 mmol/L) or *2*) taking an oral glucose-lowering medication or insulin. Use of blood pressure–lowering medication use was quantified among individuals with diabetes who also had hypertension, defined by systolic blood pressure $\geq$140 mmHg, diastolic blood pressure $\geq$90 mmHg, or current use of an antihypertensive medication. Statin use was quantified among individuals with diabetes age $\geq$40 years. As in our prior work (9), in the treatment domain, we did not restrict the denominator to individuals with diagnosed diabetes, because we were most interested in assessing the performance of health systems in delivering recommended diabetes treatments to all eligible individuals (diagnosed or undiagnosed). This approach is consistent with the WHO Package of Essential Noncommunicable Disease Interventions for Primary Health Care recommended indicator for monitoring treatment of diabetes and cardiovascular risk factors using population data (19).

In the control domain, glycemic control was quantified as HbA_{1c} $<$8.0% (FBG $<$9.2 mmol/L) among individuals with diagnosed diabetes. Blood pressure control was quantified as systolic blood pressure $<$140 and diastolic blood pressure $<$90 mmHg among individuals with diagnosed diabetes (19). Cholesterol control was defined as follows among individuals with diagnosed diabetes: *1*) In individuals age $\geq$40 years, cholesterol control was defined as self-reported statin use because the WHO recommends statin therapy for all people with diabetes in this age range without a cholesterol target (19), and *2*) in individuals age $\leq$40 years, cholesterol control was defined as total cholesterol $<$190 mg/dL based on recommended targets in the 2007 WHO guidelines on the prevention of cardiovascular disease (27). We also assessed performance measures of combined glycemic and blood pressure control (AB control; A refers to HbA_{1c}) and combined glycemic, blood pressure, and cholesterol control (ABC control) (28).

Statistical Analyses

We estimated age-adjusted differences in the proportion of individuals living in rural versus urban areas who achieved each performance measure. Specifically, we constructed survey-weighted multivariable Poisson regression models with robust standard errors adjusted for clustering at the level of the primary sampling unit and inclusion of covariates of rural versus urban residence and age. We ran the models across the overall pooled sample, across the pooled sample stratified by sex, and within each country. Age was included as a continuous variable using restricted cubic splines with five knots in pooled models and, because of smaller sample sizes, three knots in within-country models (29). In within-country models, we excluded the performance measures for statin therapy, cholesterol control, and combined ABC control, because statin use was too low in many surveys to run the regressions. In pooled models, we used country fixed effects and rescaled sample weights such that each country contributed equally. We used equal country weights because we were primarily interested in the performance of health systems in delivering diabetes care to rural populations, and therefore, our primary unit of interest was each country's health system. The large sample in the Indian survey therefore did not disproportionally affect the pooled results.

Relative differences are reported as risk ratios and absolute differences as average

marginal effects (30). The term risk refers to a desirable outcome (achievement of a diabetes performance measure) rather than an undesirable outcome. We report the age-adjusted proportion of individuals with diabetes who achieve each performance measure using average adjusted predictions (30). The implication of these results at the population level is then illustrated in a hypothetic country with the same rural-urban demographics as the pooled sample and a population of 10 million individuals. This population size was chosen because it approximates the median number of individuals age 18–69 years in 2015 among included countries (median 9.4 million) (31). A complete case analysis was used because <0.1% of respondents were missing data on rural or urban residence, and ≤1.8% of respondents were missing data on any outcome (Supplementary Material). Analyses were conducted in Stata (version 16.1).

Sensitivity Analyses

We conducted multiple sensitivity analyses. First, we directly estimated the proportion of individuals achieving each performance measure rather than using the regression-based method adjusting for age. Second, we used a stricter glycemic control target of HbA_{1c} <7.0% (FPG <8.0 mmol/L). Third, we rescaled the survey weights so that each country contributed weight in proportion to the country's 2015 population of individuals age 18–69 years (31).

Data Availability and Ethics

Statistical code is available at the Harvard Dataverse (https://doi.org/10.7910/DVN/8GMQ49). This study used survey data that could not be linked to a specific individual and was determined to be exempt from institutional ethics approval at the University of Michigan (HUM00201307), Ann Arbor, Michigan.

Data and Resource Availability

Data included in this study are publicly available for 37 of the 42 included country surveys. A complete list of web addresses and contacts regarding data access is provided in the Supplementary Material. For surveys that are not publicly accessible and for which we have arranged data-use agreements, data will be made available with permission of the data owners. Replication code is available at the Harvard Dataverse (https://doi.org/10.7910/DVN/8GMQ49).

RESULTS

Survey and Sample Characteristics

The pooled data set included surveys conducted between 2009 and 2019 in 42 LMICs, representing 69% of the total 2015 population in LMICs of individuals age 18–69 years (Table 1 and Supplementary Material). The final sample included 840,110 individuals, of whom 35,404 had diabetes (diagnosed or undiagnosed) and 16,694 had diagnosed diabetes (Supplementary Material). In the pooled sample using equal sampling weights, 54.3% (95% CI 53.1–55.5%) of the total population and 46.9% (95% CI 45.4–48.6%) of the population with diabetes lived in rural areas (Supplementary Material). The prevalence of diabetes in the pooled sample was 6.0% (95% CI 5.5–6.4%) in rural and 9.4% (95% CI 8.9–9.9%) in urban areas (Supplementary Material).

Achievement of Diabetes Performance Measures Across the Pooled Sample

Relative and absolute differences in the achievement of diabetes performance measures among rural versus urban populations across the pooled sample are shown in Fig. 1. Compared with urban populations with diabetes, rural populations with diabetes had a lower relative risk of ∼15–30% of achieving performance measures in the domains relating to diagnosis and treatment. In the control domain, compared with urban populations with diabetes, rural populations with diabetes had a 14% (95% CI 5–22%) lower relative risk of glycemic control, 6% (95% CI −5 to 16%) lower relative risk of blood pressure control, 23% (95% CI 2–39%) lower relative risk of cholesterol control, 20% (95% CI 4–34%) lower relative risk of combined AB control, and 61% (95% CI 29–78%) lower relative risk of combined ABC control.

The age-adjusted proportion of individuals with diabetes achieving performance measures is shown in Fig. 2*A*. In general, the absolute rural-urban difference among individuals with diabetes tended to be larger for performance measures with greater baseline achievement. The population implication of these results in a hypothetic country with the same rural-urban demographics as the pooled sample and a population of 10 million individuals is shown in Fig. 2*B*. In such a country, there would be 429,000 urban individuals with diabetes and 323,000 rural individuals with diabetes. Of these, 64.7% of urban individuals (n = 293,000; 95% CI 282,000–303,000) with diabetes and 49.1% of rural individuals (n = 149,000; 95% CI 140,000–157,000) with diabetes would be aware of their diagnosis. Estimates underlying Fig. 2 are found in the Supplementary Material.

Achievement of Diabetes Performance Measures Across the Pooled Sample by Sex

Men and women in rural areas compared with urban areas had similar relative underachievement of diabetes performance measures relating to the diagnosis and treatment domains (Fig. 3 and Supplementary Material). However, in the control domain, rural women tended to have much lower achievement than urban women, whereas among men, the rural-urban differences were small or even reversed. These differences in achievement by sex were especially marked for the combined outcomes.

Achievement of Diabetes Performance Measures by Country

In the within-country analyses, examples of countries that generally had fewer or no relative rural-urban differences in achievement of diabetes performance measures included Chile, El Salvador, Guyana, Jordan, and Laos. Examples of countries with larger rural-urban differences included Benin, Bhutan, Burkina Faso, Kenya, Tanzania, Turkmenistan, Uganda, and Zanzibar (Supplementary Material). Rural-urban differences in the diagnostic domain were especially marked in several of the African countries in the sample.

Sensitivity Analyses

The results from the first sensitivity analysis estimating proportions unadjusted for age and the secondary sensitivity analysis assessing a stricter glycemic target of HbA_{1c} <7.0% (FPG <8.0 mmol/L) were generally consistent with those from the main analysis. The third sensitivity analysis rescaling sample weights by population size resulted in similar rural-urban differences for most performance measures, but smaller or no differences were observed for glycemic control and combined AB

Table 1—Survey characteristics

Country[a]	ISO code	Income group[b]	Year[c]	Response rate, %[d]	Sample size, *n*[e]	Median age (range), years	Rural, %[f]	Women, %[f]
Africa								
Algeria	DZA	UMIC	2016–2017	94	5,868	41 (18–69)	34	49
Benin	BEN	LIC	2015	99	4,810	36 (18–69)	49	50
Burkina Faso	BFA	LIC	2013	99	3,945	37 (25–64)	76	53
Ethiopia	ETH	LIC	2015	96	7,711	34 (18–69)	82	44
Kenya	KEN	LIC	2015	95	3,974	36 (18–69)	61	50
Malawi	MWI	LIC	2009	96	2,805	38 (25–64)	89	50
Namibia	NAM	UMIC	2013	97	3,244	46 (35–64)	53	60
South Africa	ZAF	UMIC	2012	44	3,860	40 (18–69)	30	53
Tanzania	TZA	LIC	2012	95	4,623	41 (25–64)	69	50
Togo	TGO	LIC	2010	91	3,184	34 (18–64)	62	52
Uganda	UGA	LIC	2014	99	3,408	33 (18–69)	81	57
Zambia	ZMB	LMIC	2017	78	3,331	35 (18–69)	54	50
Zanzibar	ZAN[g]	LIC	2011	98	2,187	40 (24–64)	53	51
Americas								
Chile	CHL	UMIC	2009–2010	85	4,050	43 (18–69)	13	52
El Salvador	SLV	LMIC	2014–2015	68	4,103	40 (20–69)	43	55
Guyana	GUY	LMIC	2016	77	824	42 (18–69)	73	51
Mexico	MEX	UMIC	2018–2019	98	11,401	42 (20–69)	22	55
Eastern Mediterranean								
Afghanistan	AFG	LIC	2018	78	3,336	37 (18–69)	44	44
Iran	IRN	UMIC	2016	98	17,994	43 (18–69)	29	55
Iraq	IRQ	UMIC	2015	99	3,522	39 (18–69)	24	46
Jordan	JOR	UMIC	2019	95	3,326	40 (18–69)	16	50
Morocco	MAR	LMIC	2017	89	4,280	43 (18–69)	36	50
Sudan	SDN	LMIC	2016	95	6,452	37 (18–69)	63	44
Europe								
Armenia	ARM	LMIC	2016	42	1,746	46 (18–69)	33	40
Azerbaijan	AZE	UMIC	2017	97	2,627	47 (18–69)	46	51
Belarus	BLR	UMIC	2016	87	4,736	48 (18–69)	46	52
Georgia	GEO	LMIC	2016	76	3,155	52 (18–69)	52	52
Kyrgyzstan	KGZ	LIC	2013	100	2,482	44 (25–64)	66	48
Moldova	MDA	LMIC	2013	84	3,666	49 (18–69)	57	50
Romania	ROU	UMIC	2015–2016	69	1,685	44 (18–69)	41	53
Turkmenistan	TKM	UMIC	2018	94	3,745	40 (18–69)	52	48
South East Asia								
Bangladesh	BGD	LMIC	2018	97	6,947	38 (18–69)	80	54
Bhutan	BTN	LMIC	2014	96	2,667	39 (18–69)	69	43
India	IND	LMIC	2015–2016	98	658,709	32 (18–54)	64	47
Indonesia	IDN	LMIC	2014	83	5,459	40 (18–69)	48	51
Nepal	NPL	LIC	2019	86	5,061	40 (18–69)	91	53
Western Pacific								
Cambodia	KHM	LIC	2010	96	5,026	43 (25–64)	83	51
China	CHN	UMIC	2009	88	7,568	48 (18–69)	71	53
Fiji	FJI	UMIC	2009	72	1,189	53 (40–69)	55	57
Laos	LAO	LMIC	2013	99	2,393	39 (18–65)	69	58
Mongolia	MNG	LMIC	2019	97	5,996	41 (18–69)	37	50
Vietnam	VNM	LMIC	2015	97	3,015	44 (18–69)	65	50
Overall				95 (84–97)[h]	840,110[i]	40 (38–44)[h]	54 (41–69)[h]	51 (50–53)[h]

LIC, low-income country; UMIC, upper- and middle-income country. [a]World regions are defined by the World Health Organization. [b]Income groups are defined by the World Bank fiscal year category in the year the survey was conducted. [c]Year reflects the year(s) of survey data collection. [d]This value refers to the overall or step 1 response rate. [e]The sample includes nonpregnant individuals age 18–69 years with an available diabetes biomarker. [f]These values are weighted. [g]We use a nonofficial ISO code of ZAN for Zanzibar, which is an autonomous region of Tanzania. [h]This is the median value and interquartile range, with each country having the same weight. [i]This is the sum across all countries.

control. Full results of the sensitivity analyses are provided in the Supplementary Material.

CONCLUSIONS

In nationally representative health surveys pooled from 42 geographically diverse countries representing ~70% of the adult population in LMICs, we found that individuals with diabetes in rural

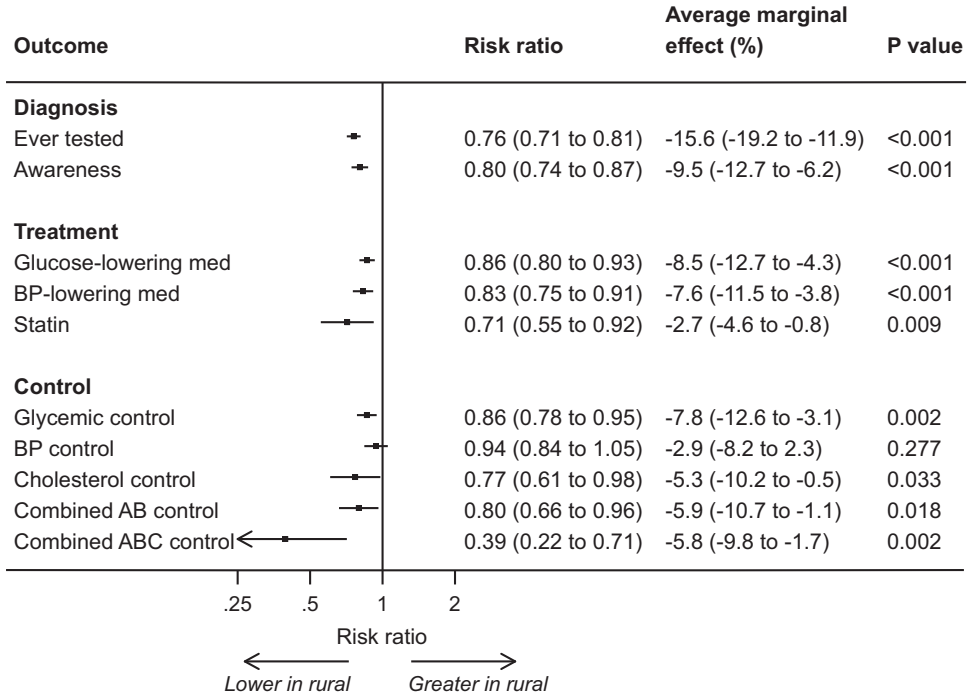

Figure 1—Differences in achievement of diabetes performance measures among rural versus urban (reference category) populations. Results are generated from survey-weighted multivariable Poisson regression models with robust SEs adjusted for clustering at the level of the primary sampling unit and inclusion of covariates of rural versus urban residence and age. Age is included as a continuous variable using restricted cubic splines with five knots at the following percentiles: 5, 27.5, 50, 72.5, and 95% (29). Error bars indicate 95% CIs. BP, blood pressure; med, medication.

compared with urban areas were less likely to achieve performance measures for the diagnosis, treatment, and control of diabetes and associated cardiovascular risk factors. We also observed that absolute levels of achievement of these performance measures were very low among both rural and urban populations with diabetes in LMICs. Our study highlights the need to strengthen primary diabetes care within health systems in LMICs and, as part of this broader effort, to consider the design of policies to address rural-urban inequities.

A surprising finding in our study was the degree to which rural-urban differences in achievement of diabetes performance measures varied by sex. In the control domain, rural-urban differences among women with diagnosed diabetes tended to be quite large, whereas these differences were attenuated or even reversed among men with diagnosed diabetes. Rural-urban differences were similar by sex for the diabetes diagnosis and treatment domains. One potential explanation for these findings is that area of residence may influence access to diabetes care differently for men versus women. Another possible explanation is that men and women have divergent patterns of underlying diabetes severity in rural versus urban areas of LMICs; sex-based differences in mean BMI have been reported across many countries (32). Adding to prior calls for research on sex-specific diabetes outcomes (33), our study suggests a need to investigate the interaction between sex and area of residence with regard to diabetes care in LMICs.

To our knowledge, our study is the largest and most comprehensive assessment of the attainment of diabetes performance measures in rural versus urban areas of LMICs. A 2011 pooled study of seven national health surveys found that individuals with diabetes in rural areas were less likely to be diagnosed in two of the included countries, but no differences were observed for diabetes treatment or control (34). Studies using national health survey data from individual countries have shown that rural residence is often associated with lower attainment of diabetes targets (35–39). The PURE (Prospective Urban Rural Epidemiology) study, conducted in up to 18 LMICs, found lower availability and affordability of glucose-lowering, blood pressure–lowering, and cardiovascular medications among rural compared with urban populations in LMICs (40–42). The rural-urban inequities in medication access observed in PURE may have contributed to the lower achievement of diabetes treatment and control measures in rural areas observed in our study. In high-income countries, similar patterns of inequitable diabetes care have been observed among rural populations with diabetes. In the U.S., adults with diabetes in rural areas compared with those in urban areas have lower receipt of routine diabetes clinical services (43), had less improvement in control of diabetes ABC risk factors from 1999 to 2018 (44), and have higher mortality (45).

Although the main objective of our study was to assess rural-urban differences in achievement of diabetes targets, it was notable that there was generally low achievement among both rural and urban populations with diabetes. In our sample of 42 LMICs, rural individuals with diabetes were less likely to achieve most performance measures. At the same time, there was a greater absolute number of individuals with diabetes in urban areas who did not achieve many of the performance measures. These results were

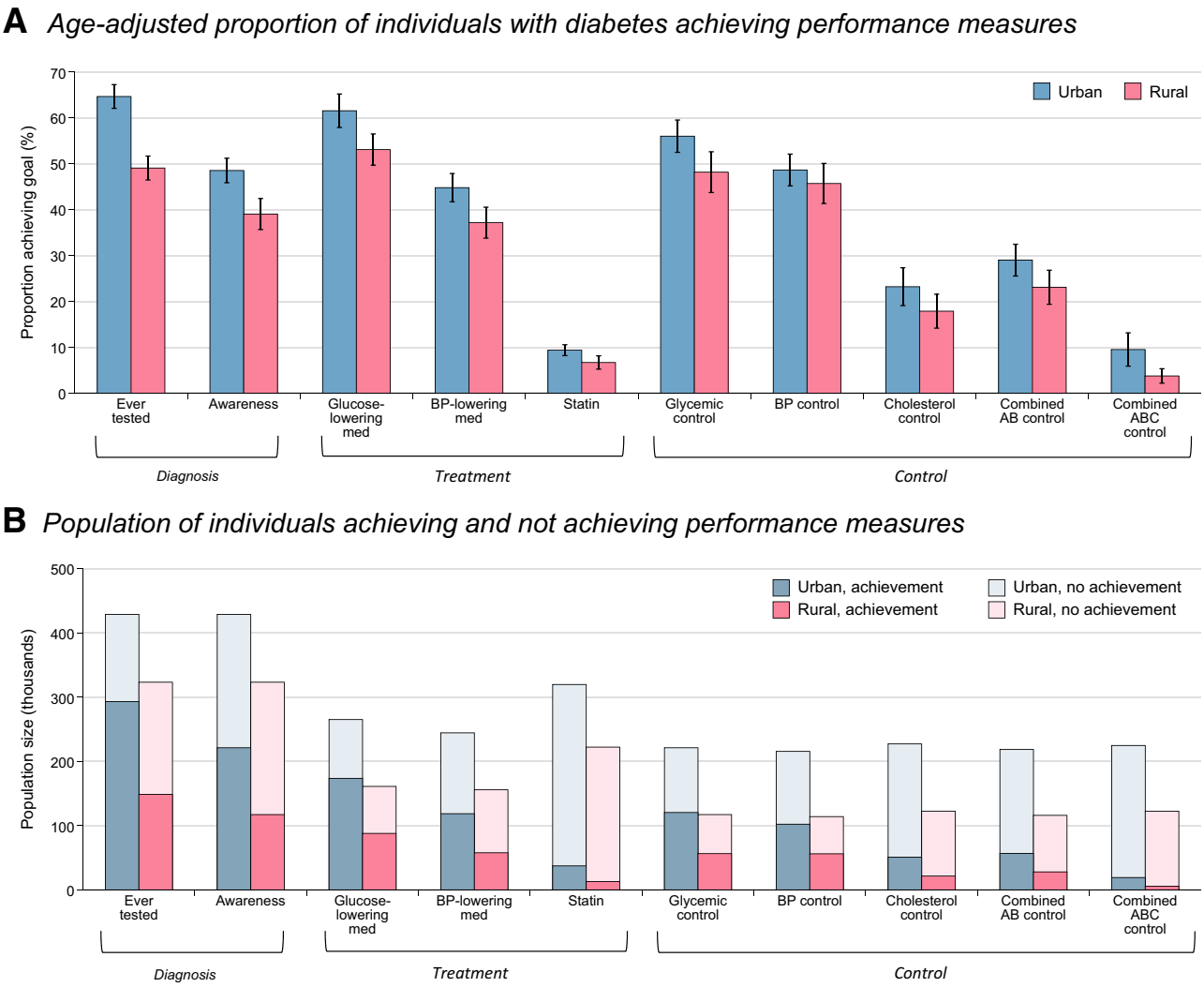

Figure 2—Diabetes performance measures among rural versus urban populations. *A*: Age-adjusted proportion of individuals with diabetes achieving performance measures are calculated as predictive margins from survey-weighted multivariable Poisson regression models with robust SEs adjusted for clustering at the level of the primary sampling unit and inclusion of covariates of rural versus urban residence and age. Estimates underlying the figure are presented in Supplementary Material. Error bars indicate 95% CIs. *B*: Population of individuals achieving and not achieving performance measures are calculated using a hypothetic country with the same rural-urban demographics as the pooled sample and a population of 10 million individuals. Estimates underlying the figure are presented in Supplementary Material. BP, blood pressure.

driven by rural-urban differences in population size and diabetes prevalence. Rural populations across the world tend to be geographically, economically, and socially marginalized (6). As such, inequities in health care for diabetes between rural and urban populations are important to document and address, even if there is a greater absolute number of individuals with diabetes living in urban rather than rural areas.

Our findings add a rural-urban dimension to prior studies from LMICs showing poor diagnosis and management of diabetes along the glycemic care cascade (7), low levels of diabetes treatment coverage (9), inadequate control of diabetes and cardiovascular risk factors (8), and infrequent achievement of guideline-recommended diabetes targets (46,47). The central policy implications of our study are *1*) that programs aiming to strengthen diabetes care in LMICs must consider the unique challenges driving inequities among rural populations with diabetes and *2*) that progress toward population-level diabetes targets should be monitored not only in national populations but also in rural and urban subpopulations.

Strengthening diabetes care in LMICs is a cross-cutting goal for multiple high-profile global health initiatives, including the primary health care movement embodied by the Alma-Ata Declaration (48), initiatives to realize universal health coverage (49), and, more recently, the launch of the WHO Global Diabetes Compact (13,14). Our study focuses on the achievement of indicators for the diagnosis, management, and control of diabetes. Within this framework, modeling studies from LMICs have shown that increasing achievement of blood pressure and statin treatment rather than improving levels of diabetes diagnosis would be most impactful in reducing diabetes complications (8). At the same time, it is important to note that diabetes diagnosis and management are not independent features of robust primary health systems. The delivery of high-quality care is likely to attract more

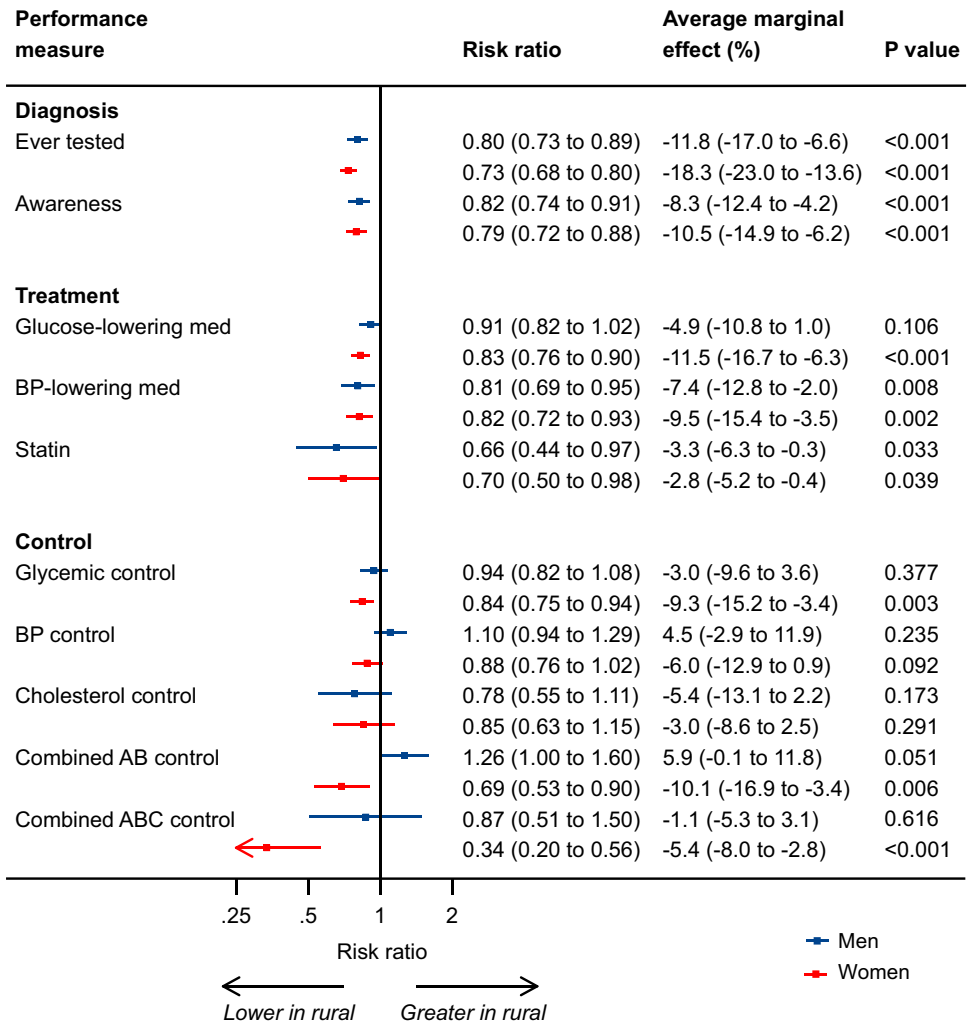

Figure 3—Differences in achievement of diabetes performance measures among rural versus urban (reference category) populations by sex. Results are generated from sex-stratified survey-weighted multivariable Poisson regression models with robust SEs adjusted for clustering at the level of the primary sampling unit and inclusion of covariates of rural versus urban residence and age. Error bars indicate 95% CIs. BP, blood pressure; med, medication.

individuals to engage in primary care; these individuals are then likely to be appropriately diagnosed, treated, and controlled; and the positive feedback loop continues as more individuals are diagnosed as they seek out trusted high-quality care. The *Lancet* Commission on Diabetes provides a health system strengthening roadmap for scaling up diabetes care in LMICs that includes investing in human resources, strengthening supply chains, redesigning primary care workflows using team-based approaches, and improving information systems (50). In rural areas, strategies to address unique challenges might include deployment of specialized nonphysician diabetes health workers (including community health workers), use of telemedicine, emphasis on simplified clinical protocols to deliver antihypertensive and statin therapy (8), implementation of point-of-care laboratory testing, incorporation of fixed-dose combination medications (polypills) into national formularies (51), and ensuring of access to insulin in rural primary care facilities through targeted investments in procurement, supply chains, and clinician training (52). Notably, many of these strategies are recommended in the WHO Hearts Technical Package for Cardiovascular Disease Management in Primary Health Care (53), and impressive implementation has been achieved in some regions of the world (54).

Our study has several limitations. First, we used each country's definition of rural or urban residence, and there were variations in definitions across countries (Supplementary Material). These definitions are constructed by national statistical offices and thus represent locally relevant classifications (26). Our approach has also been used in United Nations publications (25), the International Diabetes Federation Diabetes Atlas (1), and other studies using pooled survey data (32,55). Second, there was variation in the available diabetes biomarkers (glucose or HbA_{1c}), collection methods (capillary or venous), and accuracy and consistency of measurement devices across surveys. However, measurement variation does not systematically bias estimates of rural-urban differences, which was the main objective of this study. Third, there is a global trend toward increased urbanization, rising diabetes prevalence, and new initiatives to improve diabetes care, so our use of surveys conducted from 2009 to 2019 may not reflect the current status of diabetes performance measures in each country. Ongoing surveillance will

help document if and how these changes influence rural-urban diabetes patterns over the next decades. Fourth, the underlying surveys did not have complete data that permitted estimation of all diabetes performance measures for all included countries. Finally, it is possible that the differences in achievement of performance measures between men and women are partially attributable to collider stratification bias (56), a form of selection bias, because we defined the performance measures relating to control conditional upon a diabetes diagnosis.

In summary, we found that individuals with diabetes in rural compared with urban areas in LMICs were less likely to achieve performance measures for diagnosis, treatment, and control of diabetes and associated cardiovascular risk factors. Programs and policies aiming to strengthen global diabetes care must consider the unique challenges experienced by rural populations with diabetes.

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