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RESEARCH ARTICLE

# Multiple cardiovascular risk factor care in 55 low- and middle-income countries: A cross-sectional analysis of nationally-representative, individual-level data from 280,783 adults

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**Data Availability Statement:** Data included in this study are publicly available for 35 of the 56 countries. Microdata can be downloaded (upon

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free registration) for Bangladesh 2018, India 2015–2016, and Namibia 2013 at the following website: <https://dhsprogram.com/>. The country surveys included in this analysis that are publicly available through the STEPS Microdata repository (<https://extranet.who.int/ncdsmicrodata/index.php/catalog/STEPS>) are: Algeria 2016, Azerbaijan 2017, Belarus 2016, Benin 2015, Botswana 2014, Cambodia 2010, Eritrea 2010, Iraq 2015, Kiribati 2015, Kyrgyzstan 2013, Laos 2013, Lebanon 2017, Lesotho 2012, Marshall Islands 2017, Moldova 2013, Mongolia 2013, Morocco 2017, Myanmar 2014, Rwanda 2012, Samoa 2013, Sao Tome and Principe 2009, Solomon Islands 2015, Sri Lanka 2014, Sudan 2016, Tajikistan 2016, Tuvalu 2015, Vietnam 2015, Zambia 2017. The following five surveys can be accessed at their specific websites: Chile 2009–2010: <http://epi.minsal.cl/encuesta-ens-antteriores/>; China 2009: <http://www.cpc.unc.edu/projects/china/data>; Ecuador 2018: <http://www.ecuadorencifras.gob.ec/salud-salud-reproductiva-y-nutricion/>; Indonesia 2014: <https://www.rand.org/labor/FLS/IFLS.html>; Mexico 2009–2012: [www.enrvih-mxfls.org/english/index.html](http://www.enrvih-mxfls.org/english/index.html). For the remaining countries, please contact [ghp@hsph.harvard.edu](mailto:ghp@hsph.harvard.edu). For Guyana and St. Vincent and the Grenadines, which are member countries of the Caribbean Public Health Agency (CARPHA): Data were originally shared through a Data Use Agreement signed with the Executive Director of CARPHA and the agreement of The Ministries of Health of St. Vincent and the Grenadines and Guyana. The Chief Medical Officer of the St. Vincent and the Grenadine's Ministry of Health (Dr. Simone Keizer-Beache) can be contacted, if necessary.

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## Abstract

The prevalence of multiple age-related cardiovascular disease (CVD) risk factors is high among individuals living in low- and middle-income countries. We described receipt of healthcare services for and management of hypertension and diabetes among individuals living with these conditions using individual-level data from 55 nationally representative population-based surveys (2009–2019) with measured blood pressure (BP) and diabetes bio-marker. We restricted our analysis to non-pregnant individuals aged 40–69 years and defined three mutually exclusive groups (i.e., hypertension only, diabetes only, and both hypertension-diabetes) to compare individuals living with concurrent hypertension and diabetes to individuals with each condition separately. We included 90,086 individuals who lived with hypertension only, 11,975 with diabetes only, and 16,228 with hypertension-diabetes. We estimated the percentage of individuals who were aware of their diagnosis, used pharmacological therapy, or achieved appropriate hypertension and diabetes management. A greater percentage of individuals with hypertension-diabetes were fully diagnosed (64.1% [95% CI: 61.8–66.4]) than those with hypertension only (47.4% [45.3–49.6]) or diabetes only (46.7% [44.1–49.2]). Among the hypertension-diabetes group, pharmacological treatment was higher for individual conditions (38.3% [95% CI: 34.8–41.8] using antihypertensive and 42.3% [95% CI: 39.4–45.2] using glucose-lowering medications) than for both conditions jointly (24.6% [95% CI: 22.1–27.2]). The percentage of individuals achieving appropriate management was highest in the hypertension group (17.6% [16.4–18.8]), followed by diabetes (13.3% [10.7–15.8]) and hypertension-diabetes (6.6% [5.4–7.8]) groups. Although health systems in LMICs are reaching a larger share of individuals living with both hypertension and diabetes than those living with just one of these conditions, only seven percent achieved both BP and blood glucose treatment targets. Implementation of cost-effective population-level interventions that shift clinical care paradigm from disease-specific to comprehensive CVD care are urgently needed for all three groups, especially for those with multiple CVD risk factors.

## Introduction

Cardiovascular diseases (CVD), including ischemic heart disease and stroke, are the leading causes of morbidity and mortality worldwide. Low- and middle-income countries (LMICs)

have higher burdens of CVD [1–3], largely due to growing populations and increasing life expectancy putting more people at risk of developing multiple risk factors [4]. Coexisting CVD risk factors (e.g., hypertension, diabetes, hyperlipidemia) increase the complexity of symptom management needed to prevent further deterioration of quality of life and health [5, 6], contributing to increased morbidity and mortality [7, 8]. The rising prevalence of individuals with multiple CVD risk factors creates a growing urgency for health systems in LMICs to provide comprehensive CVD care [9–11], especially to those at highest risk, to prevent cardiovascular-related morbidity and mortality [12, 13].

The 75th World Health Assembly (2022) ratified global coverage targets for diabetes to prevent diabetes-related complications as part of high-level efforts to reach global sustainable development goals (SDG) target 3.4, which calls for a reduction in premature mortality from non-communicable diseases (NCDs) by a third by 2030 relative to 2015 levels, through diabetes prevention and management [14]. Global coverage targets were established for diabetes because it is a major obstacle to achieving SDG target 3.4 given that it is strongly associated with other CVD risk factors like hypertension and hyperlipidemia and is a leading cause of mortality [15–17]. The global diabetes coverage targets are that by 2030, 80% of people living with diabetes are clinically diagnosed; and among them, 80% have good control of glycemia (hemoglobin A<sub>1c</sub> <8%), and 80% have good control of blood pressure (<140/90 mm Hg), and 60% of those with diabetes aged 40 years or older are taking a statin; 100% of those with type 1 diabetes have access to affordable insulin and blood glucose self-monitoring [14]. These targets highlight the increasing recognition that CVD risk factors including hypertension, diabetes, and hyperlipidemia should be managed concurrently. Additionally, the Assembly agreed on recommendations to increase health systems' capacity to deliver cost-effective population-wide interventions and monitor progress towards these targets.

Recent analyses of health system performance in LMICs have largely focused on a single CVD risk factor [18–24], and found that individuals' awareness of their condition, medication use, and achievement of recommended treatment goals (i.e. improved management of their condition) are suboptimal—approximately 10% of people with hypertension and 23% of those with diabetes achieved treatment goals, respectively [18, 19, 25]. Few studies have examined the receipt of healthcare services (e.g., diagnosis and treatment) and the management of conditions for CVD risk reduction of among those with multiple CVD risk factors in LMICs [26, 27].

We examined whether individuals with both hypertension and diabetes were more likely to receive healthcare services and appropriately manage their conditions than those with just one of these conditions using individual-level data across multiple countries to provide a benchmark for the global coverage targets for diabetes by 2030 and the promotion of comprehensive CVD care. We also assessed appropriate management of hyperlipidemia with lipid-lowering medications (statins) as part of diabetes management according to World Health Organization (WHO) guidance [28, 29].

## Methods

### Study design and participants

We analyzed pooled, cross-sectional survey data identified through the Global Health and Population Project on Access to Care for Cardiometabolic Disease (HPACC)'s search methodology [30] that: (1) were conducted in 2009 or later in an LMIC as classified by the World Bank in the survey year; (2) were nationally representative; (3) had individual-level data available; (4) contained physiological measures of blood pressure (BP) and either blood glucose

(BG) or hemoglobin A1c (HbA1c); and (6) had a response rate of  $\geq 50\%$ . This resulted in 55 eligible surveys conducted during 2009–2019, most of which ( $n = 47$ ) used the WHO recommended Stepwise Approach to Non-Communicable Disease (NCD) Risk Factor Surveillance (STEPS) instruments for population monitoring of NCD targets.

Our sample consisted of non-pregnant individuals 40–69 years to align with the STEPS surveys inclusion criteria, most of which set an age limit of 69, and CVD management recommendation by the WHO Package of Essential Noncommunicable (PEN) Disease Interventions for primary health care in low-resource settings [28]. The PEN outlines instructions for the assessment, diagnosis, treatment, and management of diabetes and hypertension, aligning with leading clinical guidelines and prevention recommendations [28, 31, 32].

## Outcomes and procedures

We defined three mutually-exclusive study groups—namely hypertension only, diabetes only, and both hypertension and diabetes (henceforth referred to as hypertension-diabetes)—to compare individuals with concurrent hypertension and diabetes to individuals with each of these conditions separately. *Hypertension* was defined as either: systolic BP (SBP)  $\geq 140$  mmHg or diastolic BP (DBP)  $\geq 90$  mmHg as per survey biomarker measurement, self-reported antihypertensive medication use, or self-reported diagnosis by a clinician [28]. *Diabetes* was defined as either: fasting plasma glucose (FPG)  $\geq 7.0$  mmol/L (126 mg/dL), random plasma glucose  $\geq 11.1$  mmol/L (200 mg/dL) or HbA1c  $\geq 6.5\%$  as per survey biomarker measurement, self-reported glucose-lowering medication use, or self-reported diagnosis by a clinician [28]. **S1–S4 Tables** provides further details the hypertension and diabetes definitions as well as the BP and diabetes biomarker measurements.

For each of these study groups, we derived four main outcomes based on the PEN recommendation and the global diabetes coverage targets: awareness of diagnosis, receipt of lifestyle counseling, receipt of pharmacological therapy, and achievement of appropriate hypertension and diabetes management (see **Table 1** and **S5 Table**).

*Awareness of diagnosis* was defined by respondents reporting having been told by a doctor or healthcare worker that they have elevated BP or BG.

The *lifestyle counseling* outcome was defined as respondents reporting to being advised to (1) start or increase physical activity, (2) reduce salt intake, or (3) maintain a healthy body weight or lose weight during any visit to a doctor or healthcare worker in the past 12 months. Physical activity and weight loss were assessed for all study groups and salt reduction was examined among those with hypertension only or hypertension-diabetes.

The *pharmacological therapy* outcome was defined as self-reported use of antihypertensive, glucose-lowering, or cholesterol-lowering (statin) medications in the past two weeks, individually or in combination. We described statin use among the diabetes only and hypertension-diabetes groups, since statins are recommended in individuals aged  $\geq 40$  years with diabetes, regardless of lipid values, for primary prevention of CVD [28].

To assess *appropriate hypertension and diabetes management*, we applied the WHO PEN recommended treatment goals to the BP and diabetes biomarker measurements [33]. The BP treatment goal was set at SBP  $< 140$  mmHg and DBP  $< 90$  mmHg. The diabetes treatment goal was based on HbA1c  $< 7.0\%$  or FPG  $< 7.0$  mmol/L ( $< 126$  mg/dl) if HbA1c was not available. We used the PEN HbA1c definition  $< 7.0\%$  rather than the global diabetes coverage target of  $< 8.0\%$  because we included adults aged 40–69 years; a higher target is often chosen as a blanket metric when older adults are part of the denominator. Among the diabetes only and hypertension-diabetes groups, we defined an additional control indicator that combined the diabetes treatment goal defined above and the self-reported use of statins.



Table 1. Definition of outcomes and the study groups among whom they were recommended.

| Outcome<br>Indicator <sup>a</sup>  | Study group <sup>b</sup> |                  |                           |
|--|--------------------------|------------------|---------------------------|
|  | Hypertension<br>Only     | Diabetes<br>Only | Hypertension-<br>Diabetes |
| <b>Diagnosis</b>   |                          |                  |                           |
| Awareness of condition   | X                        | X                | X                         |
| <i>Individuals self-reporting to have ever been told by a doctor or other health worker that they have raised blood pressure [hypertension] or raised blood glucose [diabetes]</i> |                          |                  |                           |
| <b>Treatment: lifestyle counseling</b>   |                          |                  |                           |
| Counseled to exercise  | X                        | X                | X                         |
| Counseled to maintain a healthy body weight or lose weight   | X                        | X                | X                         |
| Counseled to reduce salt intake  | X                        |                  | X                         |
| <b>Treatment: pharmacological therapy use<sup>†</sup></b>  |                          |                  |                           |
| Antihypertensive   | X                        |                  | X                         |
| Glucose-lowering   |                          | X                | X                         |
| <i>Oral glucose-lowering medication or insulin</i>   |                          |                  |                           |
| Antihypertensive & Glucose lowering  |                          |                  | X                         |
| Cholesterol-lowering (statin)  |                          | X                | X                         |
| <b>Management targets</b>  |                          |                  |                           |
| Blood pressure (BP)  | X                        |                  | X                         |
| <i>Individuals with systolic BP &lt;140 mmHg &amp; diastolic BP &lt;90 mmHg</i>  |                          |                  |                           |
| Blood glucose (BG)   |                          | X                | X                         |
| <i>Individuals with HbA1c &lt;7.0% or FPG &lt;7.0 mmol/L (&lt;126 mg/dl) if HbA1c not available</i>  |                          |                  |                           |
| BP & BG  |                          |                  | X                         |
| BG & statin use  |                          | X                | X                         |
| BP, BG, & statin use   |                          |                  | X                         |

Abbreviations: FPG, fasting plasma glucose; HbA1c, hemoglobin A1c; mg/dl, milligram/deciliter; mmHg, millimeter of mercury; mmol/L, millimole/liter.

<sup>a</sup>All indicators were assessed in the 55 countries included in this analysis, except for the lifestyle counseling indicators (33–34 countries) and indicators that include status use (34 countries).

<sup>b</sup>Individuals with *hypertension only* were those with blood pressure  $\geq 140/90$  mmHg or self-reported antihypertensive medication use or self-reported diagnosis by a clinician, without diabetes. Individuals with *diabetes only* were those with a FPG of 7.0 mmol/L (126 mg/dL) or above, random plasma glucose 11.1 mmol/L (200mg/dL) or above, an HbA1c measurement of 6.5% or above or self-reporting using glucose-lowering medications or self-reported diagnosis by a clinician, without hypertension. Individuals with *hypertension and diabetes (hypertension-diabetes)* were those with concurrent hypertension and diabetes, and they were our primary study population.

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## Statistical analysis

For each group of interest, we estimated the percentage of individuals who received healthcare services and achieved condition management overall and stratified by survey implementation-year groups (2009–2014 and 2015–2019) and World Bank income group. We combined low-income ( $n = 11$ ) and lower-middle-income ( $n = 26$ ) countries because of data sparsity and reported stratified results as low/lower-income countries (L-MICs) and upper-middle-income countries (UMICs).

In all analyses, we accounted for the complex survey design by adjusting for stratification and clustering at the primary sampling unit (PSU) using the ‘srvyr’ R package [34]. Additionally, we used sampling weights adjusting for selection probability, nonresponse, and differences between the sample and target population. The main interest of our analysis is at the health system level; therefore, we rescaled survey weights to ensure equal contribution of each survey. If survey weights were missing but biomarker information was available, the country-average weight was assigned. For all other data, we did not replace or impute missing values.

All models also include countries as indicator variables. We included only individuals with all relevant covariate and indicator data for each outcome analysis. Analyses were done in R version 4.1.2 [35].

### Exploratory analysis

In addition to the risk factor approach (hypertension and diabetes), we also considered the total risk approach, the preferred strategy [36] to identify those at high risk of debilitating (e.g., heart attacks, strokes, etc.) and fatal CVD outcomes. The total risk approach considers several risk factors including age, biological sex, body mass index (BMI), tobacco use, diabetes diagnosis, BP, and blood cholesterol to calculate a 10-year CVD risk score [37]. We estimated the percentage of individuals who received healthcare services and achieved appropriate management goals in the hypertension-diabetes group among those with 10-year CVD risk score <10% and ≥10%. We used the 2019 WHO office-based risk equations to estimate 10-year CVD risk [37].

### Ethics

The institutional review board at the University of North Carolina at Chapel Hill approved this study as exempt because of the use of de-identified data (Exemption # 21–2860).

### Results

Of the 55 included countries, 37 were L-MICs and 19 UMICs (Table 2) and the average response rate was 86.7%. The pooled sample included 280,783 non-pregnant individuals. Of those, 90,086 (38.8% of the population-weighted sample) lived with hypertension only, 11,975 (4.9%) lived with diabetes only, and 16,228 (9.3%) lived with hypertension-diabetes (Table 3). The hypertension-diabetes group had the highest weighted percentage of individuals who were aged 60–69 years (30.1%), women (57.3%), and had a BMI ≥ 30 kg/m<sup>2</sup> (47.3%); however, they also had the lowest weighted percentage of individuals who were current tobacco smokers (15.3%). The share of missing values for each characteristic and outcome are provided by country in S6 and S7 Tables, respectively.

In Fig 1 we show the percentage of individuals who received healthcare services and achieved appropriate management across the three study groups in the pooled country sample. Among the hypertension-diabetes group, 64.1% (95% CI: 61.8–66.4) were diagnosed with both conditions, which was more than sixteen percentage points higher than those diagnosed in the hypertension only (47.4% [95% CI: 45.3–49.6]) and diabetes only (46.7% [95% CI: 44.1–49.2]) groups (Fig 1A). Across the three lifestyle counseling indicators, the hypertension-diabetes group reported a higher uptake of lifestyle counseling than the hypertension only and diabetes only groups. For example, more than half of those in the hypertension-diabetes group (55.8% [95% CI: 52.1–59.5]) reported receiving exercise counseling compared to 39.7% (95% CI: 38.3–41.0) and 42.3% (95% CI: 38.9–45.7) of those in the hypertension only and diabetes only groups, respectively (Fig 1B).

Medication use was low in all three groups with 20–30% taking treatment, and this was no different across groups (Fig 1C). When disaggregating the combined pharmacological therapy indicator in the hypertension-diabetes group, no individual condition was more likely to be treated (38.3% [95% CI: 34.8–41.8] using antihypertensive and 42.3% [95% CI: 39.4–45.2] using glucose-lowering medications); however, the treatment usage was higher for each of the individual conditions than both conditions (24.6% [95% CI: 22.1–27.2]). Statin use was 9.5% (95% CI: 8.3–10.7) in the hypertension-diabetes group, which was more than double that of the statin use in the diabetes only group (4.6% [95% CI: 3.5–5.6]).

Table 2. Survey characteristics.

| Geographic region and country                 | Income group | Year    | Response rate, (%) | N, after exclusion <sup>a</sup> | Female, (%) | Median age, years (IQR) |
|---|--------------|---------|--------------------|---------------------------------|-------------|-------------------------|
| <b><i>East, South, and Southeast Asia</i></b> |              |         |                    |                                 |             |                         |
| Bangladesh                                    | L-MIC        | 2018    | 83.3               | 3,235                           | 48.3        | 49 (44–56)              |
| Bhutan  | L-MIC        | 2014    | 96.9               | 1,307                           | 57.6        | 50 (45–57)              |
| Cambodia                                      | L-MIC        | 2010    | 96.3               | 3,077                           | 65.4        | 50 (45–56)              |
| India   | L-MIC        | 2015–16 | 97.6               | 175,222                         | 82.6        | 45 (42–47)              |
| Indonesia                                     | L-MIC        | 2014    | 90.5               | 2,719                           | 57.8        | 56 (47–61)              |
| Laos  | L-MIC        | 2013    | 99.2               | 1,162                           | 58.0        | 49 (44–55)              |
| Myanmar                                       | L-MIC        | 2014    | 94.0               | 5,219                           | 65.5        | 51 (45–57)              |
| Nepal   | L-MIC        | 2019    | 86.4               | 2,468                           | 58.8        | 51 (45–60)              |
| Sri Lanka                                     | L-MIC        | 2014    | 72.0               | 2,586                           | 59.8        | 53 (46–60)              |
| Timor-Leste                                   | L-MIC        | 2014    | 96.3               | 1,211                           | 52.8        | 51 (44–61)              |
| Vietnam                                       | L-MIC        | 2015    | 97.4               | 1,842                           | 56.9        | 52 (45–59)              |
| <b><i>Europe and Central Asia</i></b>         |              |         |                    |                                 |             |                         |
| Azerbaijan                                    | UMIC         | 2017    | 97.3               | 1,694                           | 60.0        | 55 (48–60)              |
| Belarus                                       | UMIC         | 2016    | 87.1               | 3,288                           | 59.7        | 54 (47–61)              |
| Georgia                                       | L-MIC        | 2016    | 75.7               | 2,297                           | 73.0        | 56 (49–63)              |
| Kyrgyzstan                                    | L-MIC        | 2013    | 100.0              | 1,556                           | 63.2        | 51 (46–57)              |
| Moldova                                       | L-MIC        | 2013    | 83.5               | 2,404                           | 63.9        | 55 (49–62)              |
| Mongolia                                      | L-MIC        | 2013    | 97.4               | 971                             | 57.4        | 49 (44–54)              |
| Romania                                       | UMIC         | 2015–16 | 69.1               | 1,017                           | 53.5        | 54 (46–62)              |
| Tajikistan                                    | L-MIC        | 2016    | 94.0               | 1,258                           | 56.8        | 50 (45–57)              |
| <b><i>Latin America and the Caribbean</i></b> |              |         |                    |                                 |             |                         |
| Chile   | UMIC         | 2009–10 | 85.0               | 2,345                           | 60.2        | 53 (46–60)              |
| Costa Rica                                    | UMIC         | 2010    | 87.8               | 1,452                           | 75.1        | 52 (46–60)              |
| Ecuador                                       | UMIC         | 2018    | 69.4               | 2,040                           | 56.9        | 52 (46–60)              |
| Guyana  | UMIC         | 2016    | 77.0               | 442                             | 61.1        | 52 (46–59)              |
| Mexico  | UMIC         | 2009–12 | 90.0               | 4,868                           | 54.9        | 54 (48–60)              |
| St. Vincent & the Grenadines                  | UMIC         | 2013    | 67.8               | 594                             | 57.4        | 52 (46–59)              |
| <b><i>Middle East and North Africa</i></b>    |              |         |                    |                                 |             |                         |
| Algeria                                       | UMIC         | 2016    | 93.8               | 3,131                           | 54.2        | 50 (44–58)              |
| Iran  | UMIC         | 2016    | 98.4               | 10,309                          | 54.1        | 52 (45–59)              |
| Iraq  | UMIC         | 2015    | 98.8               | 1,730                           | 58.7        | 50 (44–59)              |
| Lebanon                                       | UMIC         | 2017    | 65.9               | 790                             | 62.7        | 52 (47–58)              |
| Morocco                                       | L-MIC        | 2017    | 89.0               | 2,484                           | 62.9        | 52 (46–60)              |
| <b><i>Oceania</i></b>                         |              |         |                    |                                 |             |                         |
| Kiribati                                      | L-MIC        | 2015    | 55.0               | 528                             | 54.5        | 50 (45–57)              |
| Marshall Islands                              | UMIC         | 2017    | 92.3               | 1,146                           | 50.0        | 50 (44–57)              |
| Samoa   | L-MIC        | 2013    | 64.0               | 702                             | 62.0        | 50 (45–56)              |
| Solomon Islands                               | L-MIC        | 2015    | 58.4               | 824                             | 50.2        | 50 (45–58)              |
| Tuvalu  | UMIC         | 2015    | 76.0               | 545                             | 55.6        | 54 (47–59)              |
| Vanuatu                                       | L-MIC        | 2011    | 94.0               | 2,262                           | 47.1        | 50 (44–56)              |
| <b><i>Sub-Saharan Africa</i></b>              |              |         |                    |                                 |             |                         |
| Benin   | L-MIC        | 2015    | 98.6               | 1,978                           | 48.5        | 50 (44–56)              |
| Botswana                                      | UMIC         | 2014    | 63.0               | 1,280                           | 70.7        | 51 (45–58)              |
| Burkina Faso                                  | L-MIC        | 2013    | 99.1               | 1,697                           | 48.0        | 49 (44–55)              |
| Comoros                                       | L-MIC        | 2011    | 96.5               | 1,233                           | 72.2        | 50 (44–57)              |
| Eritrea                                       | L-MIC        | 2010    | 97.0               | 2,933                           | 65.5        | 51 (45–60)              |

(Continued)



Table 2. (Continued)

| Geographic region and country | Income group | Year    | Response rate, (%) | N, after exclusion <sup>a</sup> | Female, (%) | Median age, years (IQR) |
|-------------------------------|--------------|---------|--------------------|---------------------------------|-------------|-------------------------|
| Eswatini                      | L-MIC        | 2014    | 76.0               | 1,025                           | 68.3        | 52 (45–60)              |
| Kenya                         | L-MIC        | 2015    | 93.0               | 1,601                           | 59.3        | 51 (44–59)              |
| Lesotho                       | L-MIC        | 2012    | 80.0               | 1,116                           | 67.7        | 52 (46–59)              |
| Liberia                       | L-MIC        | 2011    | 87.1               | 534                             | 50.2        | 48 (43–55)              |
| Namibia                       | UMIC         | 2013    | 95.8               | 2,464                           | 58.4        | 49 (44–55)              |
| Rwanda                        | L-MIC        | 2012    | 99.8               | 2,270                           | 64.4        | 49 (44–56)              |
| São Tomé and Príncipe         | L-MIC        | 2009    | 95.0               | 897                             | 61.9        | 49 (44–55)              |
| Seychelles                    | UMIC         | 2013    | 73.0               | 851                             | 56.2        | 52 (46–57)              |
| Sudan                         | L-MIC        | 2016    | 95.0               | 2,909                           | 57.9        | 50 (45–58)              |
| Tanzania                      | L-MIC        | 2012    | 94.7               | 2,499                           | 50.5        | 49 (44–56)              |
| Togo                          | L-MIC        | 2010    | 91.0               | 1,170                           | 48.2        | 48 (44–55)              |
| Uganda                        | L-MIC        | 2014    | 92.2               | 1,185                           | 60.3        | 50 (44–57)              |
| Zambia                        | L-MIC        | 2017    | 74.0               | 1,280                           | 63.5        | 50 (44–59)              |
| Zanzibar                      | L-MIC        | 2011    | 91.0               | 1,136                           | 58.5        | 49 (45–55)              |
| <b>Global</b>                 |              | 2009–19 | 86.7               | 280,783                         | 73.6        | 45 (42–49)              |

Abbreviation: L-MIC: Low/lower-income countries; UMIC: Upper-middle-income countries.

<sup>a</sup>Individuals aged 25–69 years old with non-missing diabetes biomarkers and blood pressure measurements who reported not being pregnant were included.

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The percentage of individuals who achieved appropriate management targets was lower among the hypertension-diabetes group (6.6% [95% CI: 5.4–7.8]) than the hypertension only (17.6% [95% CI: 16.4–18.8]) and diabetes only (13.3% [95% CI: 10.7–15.8]) groups (Fig 1D).

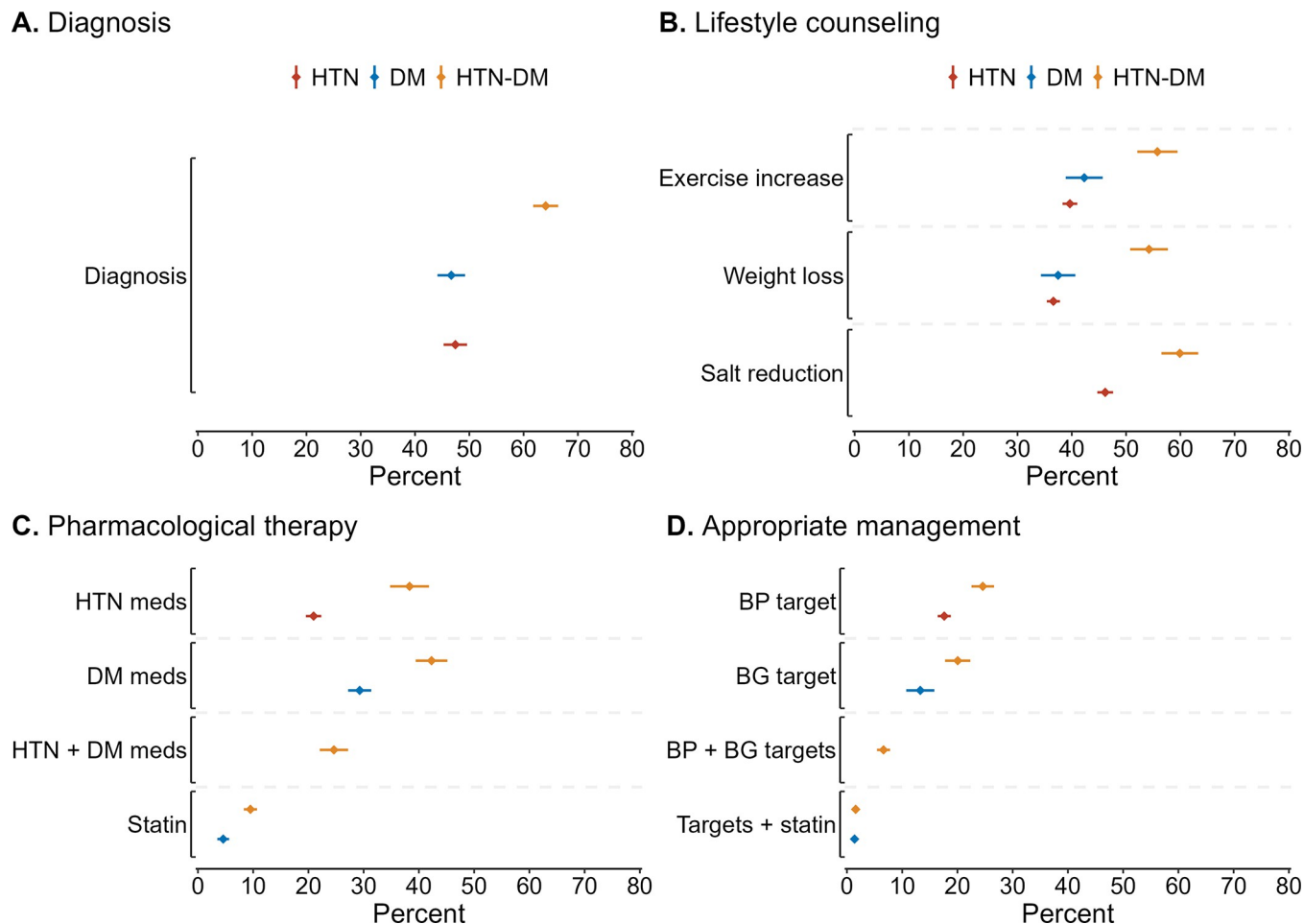
Table 3. Individual characteristics of overall sample<sup>a</sup>.

| Characteristic                | Total Pooled Sample |             | Hypertension Only |             | Diabetes Only |             | Hypertension-Diabetes |             |
|-------------------------------|---------------------|-------------|-------------------|-------------|---------------|-------------|-----------------------|-------------|
|                               | Unweighted, N       | Weighted, % | Unweighted, N     | Weighted, % | Unweighted, N | Weighted, % | Unweighted, N         | Weighted, % |
| <b>Overall<sup>b</sup></b>    | 280,783             |             | 89,906            |             | 11,958        |             | 16,210                |             |
| <b>Female</b>                 | 205,591             | 52.8        | 64,655            | 54.1        | 7,979         | 53.2        | 10,908                | 57.5        |
| <b>Age (years)</b>            |                     |             |                   |             |               |             |                       |             |
| 40–49                         | 211,925             | 48.0        | 60,933            | 41.0        | 8,171         | 45.3        | 7,979                 | 28.6        |
| 50–59                         | 45,559              | 33.9        | 17,867            | 36.8        | 2,557         | 36.6        | 4,579                 | 41.4        |
| 60–69                         | 23,300              | 18.1        | 11,106            | 22.2        | 1,230         | 18.1        | 3,652                 | 30.1        |
| <b>Education</b>              |                     |             |                   |             |               |             |                       |             |
| No schooling                  | 107,461             | 22.2        | 30,657            | 21.4        | 3,348         | 15.3        | 3,905                 | 16.0        |
| Primary                       | 66,361              | 36.9        | 22,563            | 36.7        | 3,189         | 37.1        | 4,606                 | 35.9        |
| Secondary or higher           | 105,962             | 40.9        | 36,338            | 41.9        | 5,337         | 47.6        | 7,552                 | 48.1        |
| <b>BMI (kg/m<sup>2</sup>)</b> |                     |             |                   |             |               |             |                       |             |
| <18.5                         | 31,744              | 6.6         | 6,426             | 4.5         | 811           | 3.6         | 355                   | 1.3         |
| 18.5–<25.0                    | 140,762             | 40.3        | 39,084            | 34.7        | 4,798         | 31.6        | 4,226                 | 19.8        |
| 25.0–<30.0                    | 69,850              | 28.8        | 27,025            | 30.9        | 3,864         | 33.5        | 5,742                 | 31.3        |
| ≥30.0                         | 36,962              | 24.3        | 16,875            | 29.9        | 2,353         | 31.3        | 5,684                 | 47.6        |
| <b>Current tobacco smoker</b> | 62,926              | 20.3        | 18,517            | 18.0        | 2,509         | 21.1        | 2,555                 | 15.2        |

<sup>a</sup>Individuals aged <69 years old with non-missing diabetes biomarkers and blood pressure measurements who reported not being pregnant were included. Proportions are calculated using weights provided by the individual surveys, readjusted such that each country is weighted equally.

<sup>b</sup>Among the total pooled sample, 89,906 (38.9% of the population-weighted sample) lived with hypertension only, 11,958 (4.9%) lived with diabetes only, and 16,210 (9.4%) lived with both hypertension and diabetes (hypertension-diabetes).

<https://doi.org/10.1371/journal.pgph.0003019.t003>



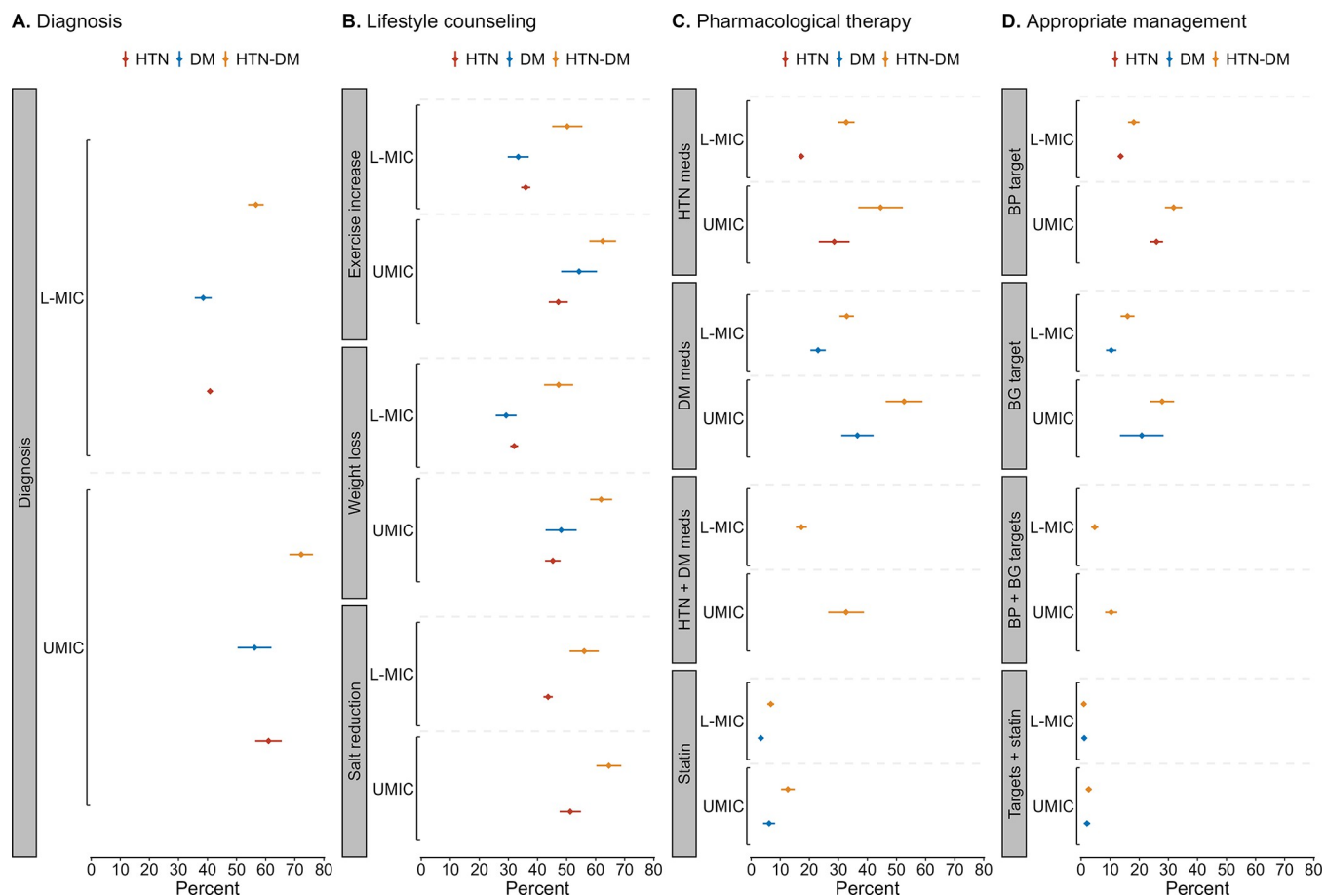
**Fig 1.** (A) The percentage of individuals who were aware of their condition (diagnosed), (B) received lifestyle counseling, (C) used pharmacological therapy and (D) achieved treatment control targets for cardiovascular disease risk reduction among those with hypertension only, diabetes only, and hypertension-diabetes in 55 low- and middle-income countries. *Abbreviations:* BG, **blood** glucose; BP, blood pressure; CVD, cardiovascular disease; DM, diabetes mellitus; HTN, hypertension; meds, medications.

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When accounting for statin use as part of appropriate management in the 34 countries where these data were available, a substantially smaller share of the hypertension-diabetes (1.6% [95% CI: 1.1–2.0]) and diabetes only (1.4% [95% CI: 0.8–1.9]) groups achieved targets (**Fig 1D**).

When stratified by World Bank income group, the percentage of individuals who received healthcare services and achieved appropriate management targets was higher in upper-middle-income than low- or lower-middle-income countries for all three groups (**Fig 2**). We did not observe statistically significant differences in outcomes (diagnosis, treatment, and appropriate management) between surveys conducted during 2009–2014 and 2015–2019 (**S9 Table**).

In our exploratory analysis conducted among the hypertension-diabetes group, most (71.5% [95% CI: 69.5, 73.4]) had an estimated predicted CVD risk score  $\geq 10\%$  (**S8 Table**). There were no differences in diagnosis awareness and receipt of lifestyle counseling outcomes between those with a CVD risk score  $< 10\%$  versus  $\geq 10\%$  (**Fig 3**). Those with CVD risk score  $\geq 10\%$  (24.4% [95% CI: 21.7–27.1]) were slightly more likely to report using antihypertensive and glucose-lowering medications than those with CVD risk score  $< 10\%$  (18.4% [95% CI: 15.1–21.6]). However, those with CVD risk score  $\geq 10\%$  (4.7% [95% CI: 3.4–5.9]) were less



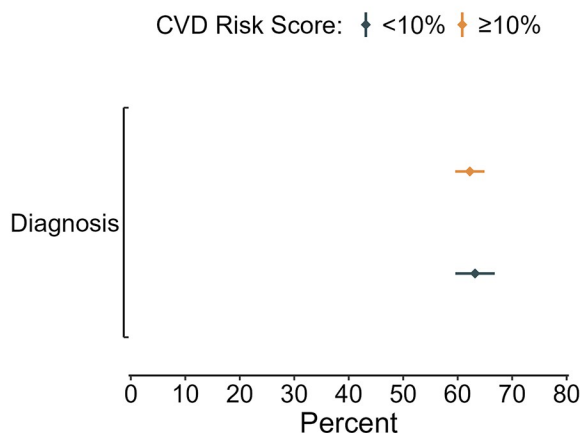
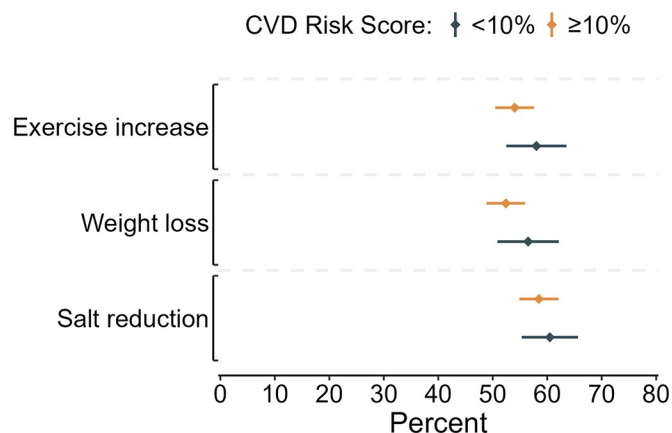
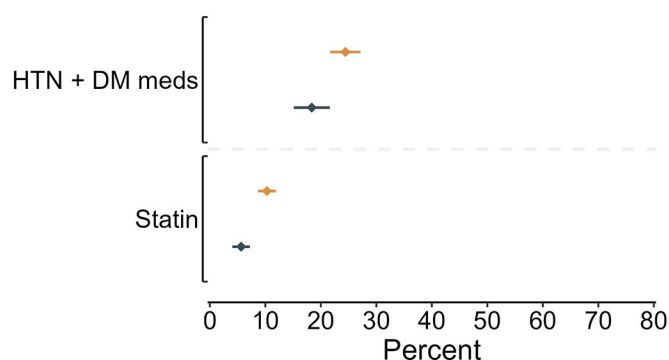
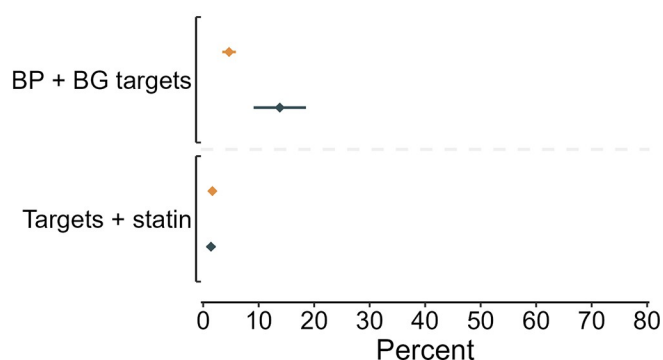
**Fig 2.** (A) The percentage of individuals who were aware of their condition (diagnosed), (B) received lifestyle counseling, (C) used pharmacological therapy, and (D) achieved treatment control targets for cardiovascular disease risk reduction among those with hypertension only, diabetes only, and hypertension-diabetes in 55 low- and middle-income countries, by World Bank income group. Abbreviations: BG, blood glucose; BP, blood pressure; CVD, cardiovascular disease; DM, diabetes mellitus; HTN, hypertension; meds, medications; L-MIC, low-/lower middle-income countries; UMIC, upper-middle-income countries.

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likely to achieve the appropriate hypertension and diabetes management targets than those with CVD risk score <10% (13.8% [95% CI: 9.1–18.5]).

## Discussion

Our study of nationally representative, individual-level data from 55 LMICs shows that health systems in LMICs are reaching a larger share of people living with both hypertension and diabetes—those with highest risk of poor CVD-related health outcomes—compared to those with either hypertension or diabetes alone. However, we also found substantial unmet need for all forms of clinical care in people with both risk factors. Only one in four people with both conditions used medications to address these risk factors. Additionally, less than 10% achieved both BP and BG management targets, and this figure dropped to 1.6% after accounting for statin use, which was low overall (5% in the diabetes-only and 10% in the hypertension-diabetes group). Finally, fewer than one in five people in each of the three study groups achieved appropriate risk factor management targets. Findings suggest an urgent need to implement cost-effective population-level interventions that shift the clinical care paradigm from disease-specific care to comprehensive CVD care for all three groups, especially for those with multiple CVD risk factors [38].

**A. Diagnosis****B. Lifestyle counseling****C. Pharmacological therapy****D. Appropriate management**

**Fig 3.** (A) The percentage of individuals who were aware of their condition (diagnosed), (B) received lifestyle counseling, (C) used pharmacological therapy, and (D) achieved treatment control targets for cardiovascular disease risk reduction among those with hypertension-diabetes 10-year predicted CVD risk score <10% versus ≥10% in 55 low- and middle-income countries<sup>a</sup>. Abbreviations: BG, blood glucose; BP, blood pressure; CVD, cardiovascular disease; DM, diabetes mellitus; HTN, hypertension; meds, medications. <sup>a</sup>We used 2019 WHO office-based risk equations to estimate 10-year CVD risk [37].

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Evidence from LMICs suggests that individuals with multiple conditions, including hypertension and diabetes, have more interactions with the health system [13, 39]. The coexistence of these conditions exacerbates poorer health status, requiring individuals to seek both primary and secondary preventative care, while simultaneously providing the health system with more opportunities to diagnose and deliver care [6]. Previous studies in LMICs have quantified the number of interactions and cost of healthcare utilization among those with multiple CVD risk factors [13, 38, 40]. Our study expands upon this literature by showing that the share of people achieving appropriate BP and BG management targets is low in individuals with hypertension only, diabetes only, and hypertension-diabetes, despite greater receipt of healthcare services among those with both conditions.

Among the hypertension-diabetes group, a greater proportion reported receiving lifestyle counseling than pharmacological therapies (e.g., increase exercise: 56% versus concurrent anti-hypertensive and glucose-lowering medication use: 25%). This may be because of reduced access to pharmacological therapies or low health literacy. Additionally, those reporting receipt of lifestyle counseling may be a younger, leaner population in whom HbA1c (or equivalent FPG) is <8% or BP <150/95 mmHg and their clinicians are willing to counsel on lifestyle

change as recommended by country-specific and leading international guidelines [28, 33] for risk factor management [41]. Translating this evidence into health policies and clinical practice to achieve health gains is particularly challenging in LMICs because of resource constraints, prioritization, and complex societal factors such as the increasing availability and consumption of inexpensive processed foods [42–44].

Reduced availability and affordability of pharmacological therapies for CVD risk management and care in LMICs, especially when multiple treatments are required, are key contributors to the low proportion of medication use among those with multiple CVD risk factors [45, 46]. Given the effectiveness of pharmacological therapies including antihypertensive, glucose-lowering, and statin medications on CVD-related outcomes, this lack of access is consequential and associated with a higher risk of adverse health outcomes, including stroke and mortality in LMICs. Among individuals with hypertension-diabetes, medication use for one condition was higher than for both conditions. This could be driven by differential availability and affordability of antihypertensive and glucose-lowering medications [45, 46] or clinical prioritization due to symptomatic severity of one condition over the other [47] when resources are limited. Here, we found greater use of pharmacological therapy for one condition in individuals with hypertension-diabetes compared to those who had either condition alone, which suggests that people with both conditions are interacting with the health system and provided more opportunities to receive needed care. Approaches to improve access to and use of pharmacological therapies among those with multiple CVD risk factors in LMICs, including the procurement of quality-assured medications that are affordable to the greater public, should be considered and implemented [45].

Our finding that less than 10% of individuals with hypertension-diabetes achieved BP and BG management targets reflects the reality that the coexistence of these CVD risk factors dramatically increases the complexity of managing individuals' symptoms to prevent further deterioration of health and quality of life [5, 6]. However, we found that more individuals in the hypertension-diabetes group achieved control of at least one target than those in either the hypertension only or diabetes only groups. When comparing the achievement of the two targets, we noted that achieving the BG target (diabetes only: 13% and hypertension-diabetes: 20%) was less common than achieving the BP target (hypertension only: 18% and hypertension-diabetes: 25%). A recent study conducted in the UK concurs with our finding that the coexistence of multiple CVD risk factors was associated with a higher probability of achieving appropriate management [48] while others have found that individuals with hypertension-diabetes were less likely to achieve BP control [49, 50]. Nevertheless, the levels of risk factor management in all three groups in our study were lackluster, suggesting an urgent need for improvements in CVD care in LMICs.

Our study has limitations. First, our definitions of hypertension and diabetes were limited to a single time point or measurement which might have resulted in the misclassification of our three study groups. In clinical practice, hypertension management is based on BP measured during multiple consecutive healthcare visits. However, we used three BP measurements from a single occasion to diagnose hypertension [51–53], and higher thresholds for hypertension definition compared to current guidelines that use a BP >130/80 mmHg. For diabetes, most surveys collected a single capillary glucose measurement, which other studies have found to under- or over-diagnose diabetes [54]. However, biological measurements captured on a single time point are commonly used in high-quality population-based surveys to estimate disease prevalence and evaluate health system performance [55]. Additionally, we included reported diagnosis awareness and medication use in our definition to identify individuals with BP and diabetes biomarker measurements below the diagnostic thresholds who may have benefited from lifestyle counseling and pharmacological therapies and, therefore, would not be

detected based on biological measurements alone. Second, we used self-reported information to define our diagnosis awareness, lifestyle counseling, and pharmacological therapy outcomes which might lead to differential misclassification of our outcomes due to recall bias. It should be noted that prior studies have found high accuracy of self-reported CVD histories and medications [56, 57]. Third, we used data collected from surveys conducted in different countries over ten years. Although most surveys (84%) used the WHO STEPS questionnaire and similar approaches to measure BP and diabetes biomarkers, differences in the translation and phrasing of questionnaires and implementation of biological measurement procedures might have contributed to variations in our estimates. Finally, the 55 LMICs included in this study may not represent all LMICs globally and encompass a heterogeneous group of countries with different health systems. However, including them together in analyses allows us to better understand the state of CVD care for individuals at the highest risk of developing CVD-related disability and mortality in low-resource settings.

In conclusion, we found that individuals with concurrent hypertension and diabetes were more likely to have been diagnosed and treated for CVD risk factors than individuals with only one of these conditions. However, using the recently adopted global coverage targets for diabetes by 2030 as a benchmark [58], there remains a substantial gap in appropriate CVD risk factor management as less than one in ten people with concurrent risk factors achieved both BP and BG targets, and even fewer achieved these metrics along with statin use. To achieve these targets, policy efforts and investments should increase health systems' capacity to deliver cost-effective population-level interventions and shift the clinical care paradigm from disease-specific care to comprehensive care.

## Supporting information

**S1 Table. Detailed definitions the blood pressure and diabetes biomarker measurements.**  
(DOCX)

**S2 Table. Blood pressure measurement details.**  
(DOCX)

**S3 Table. Diabetes biomarker measurement details.**  
(DOCX)

**S4 Table. Lipid biomarker measurement details.**  
(DOCX)

**S5 Table. Select questions from generic STEPS surveys.**  
(DOCX)

**S6 Table. Number and percent of participants with missing predictor variables by country.**  
(DOCX)

**S7 Table. Number and percent of participants with missing outcome indicator variables by country.**  
(DOCX)

**S8 Table. Distribution of 10-year predicted cardiovascular disease (CVD) risk score among individuals with hypertension only, diabetes only and hypertension and diabetes (hypertension-diabetes).**  
(DOCX)

**S9 Table. The proportion of individuals who were aware of their condition (diagnosed), had received lifestyle counseling, used pharmacological therapy, and achieved appropriate**



**management for cardiovascular disease risk reduction among those with hypertension (HTN) only, diabetes (DM) only, and hypertension and diabetes (HTN-DM) in 55 low- and middle-income countries overall and by world bank income group and survey year groups (2009–2014 and 2015–2019).**  
(DOCX)

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## References

1. Roth GA, Mensah GA, Johnson CO, Addolorato G, Ammirati E, Baddour LM, et al. Global Burden of Cardiovascular Diseases and Risk Factors, 1990–2019: Update From the GBD 2019 Study. *J Am Coll Cardiol.* 2020; 76: 2982–3021. <https://doi.org/10.1016/j.jacc.2020.11.010> PMID: 33309175

2. Jagannathan R, Patel SA, Ali MK, Narayan KMV. Global updates on cardiovascular disease mortality trends and attribution of traditional risk factors. *Curr Diab Rep*. 2019; 19: 44. <https://doi.org/10.1007/s11892-019-1161-2> PMID: 31222515
3. Gaziano TA, Bitton A, Anand S, Abrahams-Gessel S, Murphy A. Growing epidemic of coronary heart disease in low- and middle-income countries. *Curr Probl Cardiol*. 2010; 35: 72–115. <https://doi.org/10.1016/j.cpcardiol.2009.10.002> PMID: 20109979
4. Garin N, Koyanagi A, Chatterji S, Tyrovolas S, Olaya B, Leonardi M, et al. Global Multimorbidity Patterns: A Cross-Sectional, Population-Based, Multi-Country Study. *J Gerontol A Biol Sci Med Sci*. 2016; 71: 205–214. <https://doi.org/10.1093/gerona/glv128> PMID: 26419978
5. Marengoni A, Angleman S, Melis R, Mangialasche F, Karp A, Garmen A, et al. Aging with multimorbidity: a systematic review of the literature. *Ageing Res Rev*. 2011; 10: 430–439. <https://doi.org/10.1016/j.arr.2011.03.003> PMID: 21402176
6. Forman DE, Maurer MS, Boyd C, Brindis R, Salive ME, Horne FM, et al. Multimorbidity in older adults with cardiovascular disease. *J Am Coll Cardiol*. 2018; 71: 2149–2161. <https://doi.org/10.1016/j.jacc.2018.03.022> PMID: 29747836
7. Zhang D, Tang X, Shen P, Si Y, Liu X, Xu Z, et al. Multimorbidity of cardiometabolic diseases: prevalence and risk for mortality from one million Chinese adults in a longitudinal cohort study. *BMJ Open*. 2019; 9: e024476. <https://doi.org/10.1136/bmjopen-2018-024476> PMID: 30833320
8. Bazalar-Palacios J, Jaime Miranda J, Carrillo-Larco RM, Gilman RH, Smeeth L, Bernabe-Ortiz A. Aggregation and combination of cardiovascular risk factors and their association with 10-year all-cause mortality: the PERU MIGRANT Study. *BMC Cardiovasc Disord*. 2021; 21: 582. <https://doi.org/10.1186/s12872-021-02405-8> PMID: 34876013
9. Thienemann F, Ntusi NAB, Battegay E, Mueller BU, Cheetham M. Multimorbidity and cardiovascular disease: a perspective on low- and middle-income countries. *Cardiovasc Diagn Ther*. 2020; 10: 376–385. <https://doi.org/10.21037/cdt.2019.09.09> PMID: 32420119
10. BeLue R, Okoror TA, Iwelunmor J, Taylor KD, Degboe AN, Agyemang C, et al. An overview of cardiovascular risk factor burden in sub-Saharan African countries: a socio-cultural perspective. *Global Health*. 2009; 5: 10. <https://doi.org/10.1186/1744-8603-5-10> PMID: 19772644
11. Oni T, McGrath N, BeLue R, Roderick P, Colagiuri S, May CR, et al. Chronic diseases and multi-morbidity—a conceptual modification to the WHO ICC model for countries in health transition. *BMC Public Health*. 2014; 14: 575. <https://doi.org/10.1186/1471-2458-14-575> PMID: 24912531
12. Singh K, Patel SA, Biswas S, Shivashankar R, Kondal D, Ajay VS, et al. Multimorbidity in South Asian adults: prevalence, risk factors and mortality. *J Public Health (Oxf)*. 2019; 41: 80–89. <https://doi.org/10.1093/pubmed/fty017> PMID: 29425313
13. Lee JT, Hamid F, Pati S, Atun R, Millett C. Impact of Noncommunicable Disease Multimorbidity on Healthcare Utilisation and Out-Of-Pocket Expenditures in Middle-Income Countries: Cross Sectional Analysis. *PLoS ONE*. 2015; 10: e0127199. <https://doi.org/10.1371/journal.pone.0127199> PMID: 26154083
14. Gregg EW, Buckley J, Ali MK, Davies J, Flood D, Mehta R, et al. Improving health outcomes of people with diabetes: target setting for the WHO Global Diabetes Compact. *Lancet*. 2023; 401: 1302–1312. [https://doi.org/10.1016/S0140-6736\(23\)00001-6](https://doi.org/10.1016/S0140-6736(23)00001-6) PMID: 36931289
15. NCD Countdown 2030 collaborators. NCD Countdown 2030: worldwide trends in non-communicable disease mortality and progress towards Sustainable Development Goal target 3.4. *Lancet*. 2018; 392: 1072–1088. [https://doi.org/10.1016/S0140-6736\(18\)31992-5](https://doi.org/10.1016/S0140-6736(18)31992-5) PMID: 30264707
16. NCD Countdown 2030 collaborators. NCD Countdown 2030: pathways to achieving Sustainable Development Goal target 3.4. *Lancet*. 2020; 396: 918–934. [https://doi.org/10.1016/S0140-6736\(20\)31761-X](https://doi.org/10.1016/S0140-6736(20)31761-X) PMID: 32891217
17. Dal Canto E, Ceriello A, Rydén L, Ferrini M, Hansen TB, Schnell O, et al. Diabetes as a cardiovascular risk factor: An overview of global trends of macro and micro vascular complications. *Eur J Prev Cardiol*. 2019; 26: 25–32. <https://doi.org/10.1177/2047487319878371> PMID: 31722562
18. Manne-Goehler J, Geldsetzer P, Agoudavi K, Andall-Brereton G, Aryal KK, Bicaba BW, et al. Health system performance for people with diabetes in 28 low- and middle-income countries: A cross-sectional study of nationally representative surveys. *PLoS Med*. 2019; 16: e1002751. <https://doi.org/10.1371/journal.pmed.1002751> PMID: 30822339
19. Geldsetzer P, Manne-Goehler J, Marcus M-E, Ebert C, Zhumadilov Z, Wesseh CS, et al. The state of hypertension care in 44 low-income and middle-income countries: a cross-sectional study of nationally representative individual-level data from 1.1 million adults. *Lancet*. 2019; 394: 652–662. [https://doi.org/10.1016/S0140-6736\(19\)30955-9](https://doi.org/10.1016/S0140-6736(19)30955-9) PMID: 31327566
20. Flood D, Seigle JA, Dunn M, Tschida S, Theilmann M, Marcus ME, et al. The state of diabetes treatment coverage in 55 low-income and middle-income countries: a cross-sectional study of nationally

- representative, individual-level data in 680 102 adults. *Lancet Healthy Longev.* 2021; 2: e340–e351. [https://doi.org/10.1016/s2666-7568\(21\)00089-1](https://doi.org/10.1016/s2666-7568(21)00089-1) PMID: 35211689
21. Odland ML, Bockarie T, Wurie H, Ansumana R, Lamin J, Nugent R, et al. Prevalence and access to care for cardiovascular risk factors in older people in Sierra Leone: a cross-sectional survey. *BMJ Open.* 2020; 10: e038520. <https://doi.org/10.1136/bmjopen-2020-038520> PMID: 32907906
  22. Jorgensen JMA, Hedt KH, Omar OM, Davies JI. Hypertension and diabetes in Zanzibar—prevalence and access to care. *BMC Public Health.* 2020; 20: 1352. <https://doi.org/10.1186/s12889-020-09432-8> PMID: 32887593
  23. Price AJ, Crampin AC, Amberbir A, Kayuni-Chihana N, Musicha C, Tafatatha T, et al. Prevalence of obesity, hypertension, and diabetes, and cascade of care in sub-Saharan Africa: a cross-sectional, population-based study in rural and urban Malawi. *Lancet Diabetes Endocrinol.* 2018; 6: 208–222. [https://doi.org/10.1016/S2213-8587\(17\)30432-1](https://doi.org/10.1016/S2213-8587(17)30432-1) PMID: 29371076
  24. NCD Risk Factor Collaboration (NCD-RisC). Worldwide trends in body-mass index, underweight, overweight, and obesity from 1975 to 2016: a pooled analysis of 2416 population-based measurement studies in 128·9 million children, adolescents, and adults. *Lancet.* 2017; 390: 2627–2642. [https://doi.org/10.1016/S0140-6736\(17\)32129-3](https://doi.org/10.1016/S0140-6736(17)32129-3) PMID: 29029897
  25. NCD Risk Factor Collaboration (NCD-RisC). Worldwide trends in blood pressure from 1975 to 2015: a pooled analysis of 1479 population-based measurement studies with 19·1 million participants. *Lancet.* 2017; 389: 37–55. [https://doi.org/10.1016/S0140-6736\(16\)31919-5](https://doi.org/10.1016/S0140-6736(16)31919-5) PMID: 27863813
  26. Geldsetzer P, De Neve J-W, Mohan V, Prabhakaran D, Roy A, Tandon N, et al. Health System Performance for Multimorbid Cardiometabolic Disease in India: A Population-Based Cross-Sectional Study. *Glob Heart.* 2022; 17: 7. <https://doi.org/10.5334/gh.1056> PMID: 35174048
  27. Wong EB, Olivier S, Gunda R, Koole O, Surujdeen A, Gareta D, et al. Convergence of infectious and non-communicable disease epidemics in rural South Africa: a cross-sectional, population-based multimorbidity study. *Lancet Glob Health.* 2021; 9: e967–e976. [https://doi.org/10.1016/S2214-109X\(21\)00176-5](https://doi.org/10.1016/S2214-109X(21)00176-5) PMID: 34143995
  28. World Health Organization. WHO package of essential noncommunicable (PEN) disease interventions for primary health care. Geneva: World Health Organization; 2020.
  29. World Health Organization. Diagnosis and management of type 2 diabetes (HEARTS-D). Geneva: World Health Organization; 2020.
  30. Manne-Goehler J, Theilmann M, Flood D, Marcus ME, Andall-Brereton G, Agoudavi K, et al. Data resource profile: the global health and population project on access to care for cardiometabolic diseases (HPACC). *Int J Epidemiol.* 2022. <https://doi.org/10.1093/ije/dyac125> PMID: 35762972
  31. World Health Organization. Hearts: Technical package for cardiovascular disease management in primary health care. Geneva: World Health Organization; 2016.
  32. Prabhakaran D, Anand S, Watkins D, Gaziano T, Wu Y, Mbanya JC, et al. Cardiovascular, respiratory, and related disorders: key messages from Disease Control Priorities, 3rd edition. *Lancet.* 2018; 391: 1224–1236. [https://doi.org/10.1016/S0140-6736\(17\)32471-6](https://doi.org/10.1016/S0140-6736(17)32471-6) PMID: 29108723
  33. Unger T, Borghi C, Charchar F, Khan NA, Poulter NR, Prabhakaran D, et al. 2020 international society of hypertension global hypertension practice guidelines. *Hypertension.* 2020; 75: 1334–1357. <https://doi.org/10.1161/HYPERTENSIONAHA.120.15026> PMID: 32370572
  34. Ellis GF, Schneider B. *srvyr: 'dplyr'-Like Syntax for Summary Statistics of Survey Data.* CRAN; 2021.
  35. R Core Team. *R: A language and environment for statistical computing.* Vienna, Austria: R Foundation for Statistical Computing; 2021.
  36. Lloyd-Jones DM, Braun LT, Ndumele CE, Smith SC, Sperling LS, Virani SS, et al. Use of Risk Assessment Tools to Guide Decision-Making in the Primary Prevention of Atherosclerotic Cardiovascular Disease: A Special Report From the American Heart Association and American College of Cardiology. *Circulation.* 2019; 139: e1162–e1177. <https://doi.org/10.1161/CIR.0000000000000638> PMID: 30586766
  37. WHO CVD Risk Chart Working Group. World Health Organization cardiovascular disease risk charts: revised models to estimate risk in 21 global regions. *Lancet Glob Health.* 2019; 7: e1332–e1345. [https://doi.org/10.1016/S2214-109X\(19\)30318-3](https://doi.org/10.1016/S2214-109X(19)30318-3) PMID: 31488387
  38. Basu S, Flood D, Geldsetzer P, Theilmann M, Marcus ME, Ebert C, et al. Estimated effect of increased diagnosis, treatment, and control of diabetes and its associated cardiovascular risk factors among low-income and middle-income countries: a microsimulation model. *Lancet Glob Health.* 2021; 9: e1539–e1552. [https://doi.org/10.1016/S2214-109X\(21\)00340-5](https://doi.org/10.1016/S2214-109X(21)00340-5) PMID: 34562369
  39. Zhao Y, Zhao S, Zhang L, Haregu TN, Wang H. Impacts of multimorbidity on medication treatment, primary healthcare and hospitalization among middle-aged and older adults in China: evidence from a nationwide longitudinal study. *BMC Public Health.* 2021; 21: 1380. <https://doi.org/10.1186/s12889-021-11456-7> PMID: 34253222

40. Zhao Y, Atun R, Oldenburg B, McPake B, Tang S, Mercer SW, et al. Physical multimorbidity, health service use, and catastrophic health expenditure by socioeconomic groups in China: an analysis of population-based panel data. *Lancet Glob Health*. 2020; 8: e840–e849. [https://doi.org/10.1016/S2214-109X\(20\)30127-3](https://doi.org/10.1016/S2214-109X(20)30127-3) PMID: 32446349
41. Sum G, Salisbury C, Koh GC-H, Atun R, Oldenburg B, McPake B, et al. Implications of multimorbidity patterns on health care utilisation and quality of life in middle-income countries: cross-sectional analysis. *J Glob Health*. 2019; 9: 020413. <https://doi.org/10.7189/jogh.09.020413> PMID: 31448114
42. Ali MK, Siegel KR, Chandrasekar E, Tandon N, Montoya PA, Mbanya J-C, et al. Diabetes: an update on the pandemic and potential solutions. 3rd ed. In: Prabhakaran D, Anand S, Gaziano TA, Mbanya J-C, Wu Y, Nugent R, editors. *Cardiovascular, respiratory, and related disorders*. 3rd ed. Washington (DC): The International Bank for Reconstruction and Development / The World Bank; 2017. <https://doi.org/10.1596/978-1-4648-0518-9/ch12>
43. Uthman OA, Hartley L, Rees K, Taylor F, Ebrahim S, Clarke A. Multiple risk factor interventions for primary prevention of CVD in LMIC: A cochrane review. *Glob Heart*. 2017; 12: 199–208.e8. <https://doi.org/10.1016/j.gheart.2016.03.639> PMID: 27452771
44. Popkin BM, Corvalan C, Grummer-Strawn LM. Dynamics of the double burden of malnutrition and the changing nutrition reality. *Lancet*. 2020; 395: 65–74. [https://doi.org/10.1016/S0140-6736\(19\)32497-3](https://doi.org/10.1016/S0140-6736(19)32497-3) PMID: 31852602
45. Wirtz VJ, Kaplan WA, Kwan GF, Laing RO. Access to Medications for Cardiovascular Diseases in Low- and Middle-Income Countries. *Circulation*. 2016; 133: 2076–2085. <https://doi.org/10.1161/CIRCULATIONAHA.115.008722> PMID: 27217433
46. Chow CK, Nguyen TN, Marschner S, Diaz R, Rahman O, Avezum A, et al. Availability and affordability of medicines and cardiovascular outcomes in 21 high-income, middle-income and low-income countries. *BMJ Glob Health*. 2020; 5. <https://doi.org/10.1136/bmjgh-2020-002640> PMID: 33148540
47. Kaiser AH, Hehman L, Forsberg BC, Simangolwa WM, Sundewall J. Availability, prices and affordability of essential medicines for treatment of diabetes and hypertension in private pharmacies in Zambia. *PLoS ONE*. 2019; 14: e0226169. <https://doi.org/10.1371/journal.pone.0226169> PMID: 31834889
48. Boyd CM, Fortin M. Future of multimorbidity research: how should understanding of multimorbidity inform health system design? *Public Health Rev*. 2010; 32: 451–474. <https://doi.org/10.1007/BF03391611>
49. Tapela N, Collister J, Clifton L, Turnbull I, Rahimi K, Hunter DJ. Prevalence and determinants of hypertension control among almost 100 000 treated adults in the UK. *Open Heart*. 2021; 8. <https://doi.org/10.1136/openhrt-2020-001461> PMID: 33707223
50. Majernick TG, Zacker C, Madden NA, Belletti DA, Arcona S. Correlates of hypertension control in a primary care setting. *Am J Hypertens*. 2004; 17: 915–920. <https://doi.org/10.1016/j.amjhyper.2004.05.016> PMID: 15485754
51. Wong MCS, Wang HHX, Cheung CSK, Tong ELH, Sek ACH, Cheung NT, et al. Factors associated with multimorbidity and its link with poor blood pressure control among 223,286 hypertensive patients. *Int J Cardiol*. 2014; 177: 202–208. <https://doi.org/10.1016/j.ijcard.2014.09.021> PMID: 25499379
52. Olivier S, Murray T, Matthews P, Mhlongo N, Gunda R, Baisley K, et al. Pitfalls of Single Measurement Screening for Diabetes and Hypertension in Community-Based Settings. *Glob Heart*. 2021; 16: 79. <https://doi.org/10.5334/gh.1083> PMID: 34900570
53. Stauffer F, Viswanathan B, Jean M, Kinabo P, Bovet P. Comparison between capillary glucose measured with a Contour glucometer and plasma glucose in a population survey. *LaboratoriumsMedizin*. 2016; 40. <https://doi.org/10.1515/labmed-2015-0089>
54. Ali MK, Bullard KM, Gregg EW, Del Rio C. A cascade of care for diabetes in the United States: visualizing the gaps. *Ann Intern Med*. 2014; 161: 681–689. <https://doi.org/10.7326/M14-0019> PMID: 25402511
55. Yusuf S, Islam S, Chow CK, Rangarajan S, Dagenais G, Diaz R, et al. Use of secondary prevention drugs for cardiovascular disease in the community in high-income, middle-income, and low-income countries (the PURE Study): a prospective epidemiological survey. *Lancet*. 2011; 378: 1231–1243. [https://doi.org/10.1016/S0140-6736\(11\)61215-4](https://doi.org/10.1016/S0140-6736(11)61215-4) PMID: 21872920
56. Richardson K, Kenny RA, Peklar J, Bennett K. Agreement between patient interview data on prescription medication use and pharmacy records in those aged older than 50 years varied by therapeutic group and reporting of indicated health conditions. *J Clin Epidemiol*. 2013; 66: 1308–1316. <https://doi.org/10.1016/j.jclinepi.2013.02.016> PMID: 23968693
57. Hafferty JD, Campbell AI, Navrady LB, Adams MJ, MacIntyre D, Lawrie SM, et al. Self-reported medication use validated through record linkage to national prescribing data. *J Clin Epidemiol*. 2018; 94: 132–142. <https://doi.org/10.1016/j.jclinepi.2017.10.013> PMID: 29097340
58. Wilkinson E. World Health Assembly ratifies first global diabetes targets. *Lancet Diabetes Endocrinol*. 2022; 10: 560. [https://doi.org/10.1016/S2213-8587\(22\)00192-9](https://doi.org/10.1016/S2213-8587(22)00192-9) PMID: 35785797