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Hypertension care cascades and reducing inequities in cardiovascular disease in low- and middle-income countries

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Improving hypertension control in low- and middle-income countries has uncertain implications across socioeconomic groups. In this study, we simulated improvements in the hypertension care cascade and evaluated the distributional benefits across wealth quintiles in 44 low- and middle-income countries using individual-level data from nationally representative, cross-sectional surveys. We raised diagnosis (diagnosis scenario) and treatment (treatment scenario) levels for all wealth quintiles to match the best-performing country quintile and estimated the change in 10-year cardiovascular disease (CVD) risk of individuals initiated on treatment. We observed greater health benefits among bottom wealth quintiles in middle-income countries and in countries with larger baseline disparities in hypertension management. Lower-middle-income countries would see the greatest absolute benefits among the bottom quintiles under the treatment scenario (29.1 CVD cases averted per 1,000 people living with hypertension in the bottom quintile (Q1) versus 17.2 in the top quintile (Q5)), and the proportion of total CVD cases averted would be largest among the lowest quintiles in upper-middle-income countries under both diagnosis (32.0% of averted cases in Q1 versus 11.9% in Q5) and treatment (29.7% of averted cases in Q1 versus 14.0% in Q5) scenarios. Targeted improvements in hypertension diagnosis and treatment could substantially reduce socioeconomic-based inequalities in CVD burden in low- and middle-income countries.

Cardiovascular disease (CVD) is the leading cause of death globally, with at least three-quarters of these deaths occurring in low- and middle-income countries[1]. The burden of CVD risk factors, such as hypertension, is high and rising in most low- and middle-income countries due to, notably, ongoing demographic, epidemiological and nutritional transitions[1–3]. Cost-effective interventions exist to prevent CVD through control of modifiable risk factors, which, for raised blood pressure (BP), include community-based and facility-based opportunistic screening programs and pharmacological treatment with anti-hypertensive medicines[4].

Transitioning to primary care-oriented health systems able to manage patients with chronic disease over long time periods is necessary to reduce morbidity and mortality due to chronic conditions[5–7]. However, there is considerable health system underperformance for diagnosing, treating and controlling CVD risk factors across and within countries, with major implications for equity[8,9]. For example, across 44 low- and middle-income countries, 74% of people living with hypertension had ever had their BP measured, 39% had been diagnosed with hypertension, 30% had received treatment and 10% had achieved hypertension control[10]. Similarly poor performance for management of diabetes and hypercholesterolemia exists across low- and middle-income countries, leading to substantial avoidable morbidity and mortality[11–15].

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Globally, the unequal burden of chronic conditions among poor households perpetuates cycles of poverty and ill health[16]. Inequalities exist across socioeconomic groups within countries in terms of the distribution in access to healthcare services, health financing and health outcomes, and the distribution in diagnosis and care for CVD risk factors, although mixed, tends to favor wealthier individuals in low- and middle-income countries[9,17–34]. There is, thus, considerable opportunity to improve performance for diagnosing, treating and controlling CVD risk factors, such as hypertension, among the poor. Although socioeconomic inequalities in hypertension control are documented, no studies have estimated the potential equity impact of improving hypertension diagnosis and treatment across socioeconomic groups in a range of low- and middle-income countries[35–39]. Whether ensuring equitable access to screening and treatment for hypertension necessarily leads to improvements in socioeconomic-based health equity remains unknown given the multifactorial nature of CVD. If, for example, differences in CVD risk across wealth quintiles is primarily driven by factors other than hypertension, such as smoking or obesity, then targeted efforts to improve hypertension management may not necessarily improve CVD risk equity. Therefore, documenting the distribution in CVD risk at baseline and in realistic improvement scenarios can inform the design of targeted primary care programs for hypertension management.

This paper aims to assess the potential equity benefits of scaling up diagnosis and treatment of hypertension in low- and middle-income countries. Specifically, we modeled improvements in hypertension care cascade performance and estimated the distributional impact on CVD cases across wealth quintiles in 44 low- and middle-income countries. The analysis leverages nationally representative, individual-level data on CVD risk factors and the hypertension care cascade disaggregated across wealth quintiles in a large and geographically varied sample of countries. The findings can be used to prioritize policies aimed at reducing the unequal burden of CVD attributable to hypertension across socioeconomic groups. The main findings and policy implications of the work are summarized in Table 1. The main steps undertaken in the modeling analysis are presented in Extended Data Fig. 1.

Table 1 | Policy summary

Background	It is unclear how improving hypertension management impacts disparities in CVD risk across socioeconomic groups in low- and middle-income countries. We simulated improvements in hypertension diagnosis and treatment levels and evaluated the distributional benefits across socioeconomic groups in 44 low- and middle-income countries.
Main findings and limitations	Targeted improvements along the hypertension care cascade can reduce socioeconomic-based CVD disparities in low- and middle-income countries. Some countries should prioritize improving both diagnosis and linkage to treatment of people living with hypertension in the bottom wealth quintiles, whereas others should prioritize raising diagnosis levels and maintaining existing linkage to treatment. This analysis focused only on improving diagnosis and pharmacological treatment for hypertension and did not include other interventions that could also reduce population-level CVD risk. The main limitations include the lack of longitudinal data that would allow for modeling of multiple cohorts over time and estimation of lifetime benefits as well as the lack of data on diabetes status and cholesterol levels that may impact baseline CVD risk estimates. We also assumed that individuals initiated on treatment would adhere to treatment and experience full CVD risk reduction benefits. Additionally, measurement error on the wealth quintile measure may lead to less pronounced equity benefits compared to a more reliable wealth measure.
Policy implications	As the burden of hypertension and associated CVDs continues to rise, prioritizing targeted hypertension management strategies that equalize diagnosis and treatment coverage levels across socioeconomic groups will improve health equity in low- and middle-income countries. Understanding how hypertension management programs can consider disparities in diagnosis and treatment coverage within countries will be critical for executing equity-sensitive hypertension management.

Results

Data from 100,874 individuals between the ages of 40 and 80 years and living with hypertension were retained in our analysis, extracted from surveys across 44 countries (Table 2 and Supplementary Table 1). Median age ranged from 45 years in Albania and India to 60 years in China. Median body mass index (BMI) ranged from 21.1 kg m^{-2} (interquartile range (IQR): 18.3–24.7) in Eritrea to 34.5 kg m^{-2} (30.8–41.4) in Samoa. Kiribati had the highest proportion of current smokers (51.0%), Eritrea the lowest (2.3%). Median systolic blood pressure (SBP) among individuals with hypertension ranged from 136 mmHg (IQR: 125–148) in Jordan to 156 mmHg (145–172) in Indonesia. Hypertension prevalence ranged from 19.5% (95% confidence interval (CI): 17.6–21.3) in Cambodia to 67.1% (64.6–69.7) in South Africa (Table 2).

Hypertension care cascade performance

Performance along the hypertension care cascade varied widely across countries and wealth quintiles. Upper-middle-income countries (UMICs) performed better than lower-middle-income countries (LMICs) and low-income countries (LICs) for all quintiles at each cascade step (Fig. 1; see country-specific cascade values in Supplementary Table 2 and Supplementary Fig. 1). UMICs had a smaller loss from diagnosis to treatment compared to LMICs and LICs but a greater drop from treated to controlled. Across all country-level income groups, the top quintiles (Q4 and Q5) tended to have better cascade outcomes at each step (Supplementary Table 3). The gap between the top and bottom quintiles along the cascade varied across countries: the largest gaps were observed in Sudan, Namibia and Timor-Leste and the smallest gaps in Morocco, Jordan and Samoa (Supplementary Table 4).

Scenario targets

The best-performing country quintile in terms of the proportion of individuals living with hypertension aware of their diagnosis was the second quintile (Q2) in the Russian Federation, with 75.8% aware. We used this as the target proportion of individuals with hypertension aware of their diagnosis for each country quintile in the diagnosis scenario. The corresponding average treatment coverage levels after applying country-quintile-specific linkage to treatment can be found in Supplementary Table 5.

The top wealth quintile (Q5) in Afghanistan was the best-performing country quintile for treatment, with 66.9% of individuals with hypertension reporting being on treatment. We used this as the target proportion of individuals with hypertension on treatment for each country quintile in the treatment scenario. The targets for the sensitivity analyses can be found in Supplementary Tables 6–9.

Impact on CVD risk disparities

The mean 10-year CVD risk was reduced across most quintiles from baseline to diagnosis and treatment scenarios (Supplementary Table 10). The gap in CVD risk comparing the bottom (Q1) and top (Q5) quintiles also reduced for most countries (Fig. 2 and Supplementary Table 11). For example, in Timor-Leste, the absolute difference in CVD risk comparing Q1 and Q5 was 6.1 percentage points (pp) at baseline, 5.3 pp in the diagnosis scenario and 3.7 pp in the treatment scenario. In Indonesia, the difference in CVD risk comparing Q1 and Q5 was 5.6 pp at baseline and 5.7 pp in the diagnosis scenario but reduced to 3.7 pp in the treatment scenario. All absolute and relative changes in CVD risk compared to baseline by quintile and scenario for each country are provided in Supplementary Tables 12 and 13 and Supplementary Fig. 1.

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Table 2 | Summary of CVD risk factors among people living with hypertension from population-based surveys in 44 low- and middle-income countries

Country	N[a]	Median age (years)	Age range (years)	Female (%)	Median BMI (IQR)	Currently smoking (%)	Median SBP (IQR)	Hypertension prevalence (95% CI)[b]	Country income group
Afghanistan	625	51	40–69	50	27.7 (24.4, 31.1)	9.9	147.0 (138.0, 157.5)	44.3 (37.2, 51.4)	Low-income
Albania	793	45	40–49	51	27.1 (25.0, 29.8)	29.2	144.3 (138.0, 152.0)	38.8 (35.5, 42.2)	Upper-middle-income
Algeria	1,192	53	40–69	50	28.2 (25.0, 32.0)	10.6	148.7 (141.3, 160.7)	42.7 (40.5, 45.0)	Upper-middle-income
Azerbaijan	727	55	40–69	54	29.4 (26.7, 32.8)	19.5	147.3 (138.3, 163.3)	47.7 (44.0, 51.4)	Upper-middle-income
Benin	912	50	40–69	52	23.6 (21.0, 28.2)	10.8	151.7 (141.3, 170.3)	44.2 (36.6, 51.9)	Low-income
Bhutan	691	51	40–69	49	24.7 (22.0, 27.7)	2.9	143.5 (133.0, 158.0)	53.6 (50.0, 57.3)	Lower-middle-income
Botswana	623	51	40–69	53	26.2 (22.7, 30.0)	22.7	149.3 (140.0, 164.0)	49.3 (43.9, 54.7)	Upper-middle-income
Brazil	12,846	57	40–79	54	27.9 (24.8, 31.3)	16.2	141.0 (130.0, 154.0)	48.2 (47.2, 49.3)	Upper-middle-income
Cambodia	613	52	40–64	51	23.1 (20.4, 25.6)	31.7	145.0 (138.0, 155.3)	19.5 (17.6, 21.3)	Low-income
China	2,398	60	40–80	50	24.5 (22.2, 27.0)	28.3	142.0 (134.0, 155.0)	36.1 (34.2, 37.9)	Upper-middle-income
Ecuador	680	56	40–69	44	29.5 (26.3, 32.5)	7.8	141.7 (131.3, 153.3)	31.1 (28.5, 33.7)	Upper-middle-income
Eritrea	639	56	40–74	69	21.1 (18.3,24.7)	2.3	147.0 (141.0, 158.5)	20.4 (18.2, 22.5)	Low-income
Eswatini	430	55	40–70	64	29.3 (25.1, 33.9)	6.4	146.5 (136.5, 164.0)	48.4 (44.1, 52.7)	Lower-middle-income
Ethiopia	628	50	40–69	40	21.5 (19.4, 24.5)	3.9	148.5 (141.5, 161.5)	26.4 (23.5, 29.4)	Low-income
Gambia	469	50	40–64	51	25.1 (22.0, 28.7)	15.4	149.0 (141.0, 166.0)	41.8 (37.4, 46.1)	Low-income
Ghana	2,234	48	40–79	46	23.4 (20.7, 27.7)	8.0	145.5 (135.5, 158.5)	47.7 (43.5, 51.9)	Lower-middle-income
India	45,906	45	40–54	37	24.3 (21.5, 27.4)	38.7	140.0 (130.7, 149.0)	27.7 (27.1, 28.2)	Lower-middle-income
Indonesia	5,444	56	40–79	61	24.2 (21.2, 27.5)	25.0	155.5 (144.5, 172.0)	44.5 (42.5, 46.4)	Lower-middle-income
Jordan	964	54	40–69	51	31.1 (27.5, 35.3)	34.4	136.0 (125.0, 148.0)	41.8 (38.8, 44.8)	Upper-middle-income
Kenya	730	51	40–69	52	24.8 (21.7, 29.2)	9.5	146.0 (138.0, 159.5)	42.0 (38.4, 45.5)	Lower-middle-income
Kiribati	187	50	40–69	54	30.7 (26.6, 35.2)	51.0	141.0 (138.0, 156.0)	49.9 (41.5, 58.3)	Lower-middle-income
Kyrgyzstan	962	52	40–64	51	29.0 (25.7, 32.7)	21.0	150.0 (139.3, 165.7)	63.8 (60.9, 66.8)	Lower-middle-income
Laos	303	51	40–64	61	25.2 (22.5, 28.2)	24.2	145.3 (136.0, 156.7)	25.9 (22.7, 29.1)	Lower-middle-income
Lesotho	389	46	40–59	56	27.2 (23.0, 31.4)	15.7	145.3 (133.0, 158.7)	34.6 (31.0, 38.2)	Lower-middle-income
Moldova	1,802	54	40–69	53	29.2 (25.7, 33.5)	18.8	153.3 (141.3, 169.3)	62.7 (59.9, 65.5)	Lower-middle-income
Morocco	1,163	57	40–79	54	27.7 (24.8, 31.2)	7.6	150.0 (141.7, 164.7)	42.5 (40.4, 44.6)	Lower-middle-income
Myanmar	1,985	51	40–64	56	24.2 (21.1, 27.8)	24.0	148.7 (137.7, 162.0)	41.8 (37.5, 46.2)	Lower-middle-income
Namibia	1,235	50	40–64	61	25.8 (21.4,31.0)	17.5	144.0 (133.0, 157.0)	48.4 (46.0, 50.9)	Upper-middle-income
Niger	549	50	40–64	42	21.3 (19.1,23.9)	3.3	154.7 (143.7, 172.0)	51.9 (48.9, 55.0)	Low-income
Russian Federation	2,157	59	40–79	63	28.9 (26.0, 32.2)	19.8	145.0 (137.5, 159.5)	53.5 (44.4, 62.5)	Upper-middle-income
Rwanda	500	51	40–64	52	22.5 (20.3, 25.2)	24.1	146.7 (137.0, 158.7)	31.4 (28.6, 34.2)	Low-income
Samoa	256	53	40–64	46	34.5 (30.8, 41.4)	19.2	148.3 (143.0, 161.0)	38.5 (35.0, 42.1)	Lower-middle-income
Sao Tome and Principe	525	51	40–64	53	24.9 (22.1, 28.9)	8.8	155.3 (143.7, 172.3)	57.0 (50.5, 63.4)	Lower-middle-income
Solomon Islands	278	51	40–69	59	29.1 (24.9, 33.5)	17.6	151.0 (141.3, 163.7)	32.5 (27.0, 38.1)	Lower-middle-income
South Africa	2,289	57	40–79	58	28.6 (24.5, 34.1)	21.5	145.5 (134.0, 160.5)	67.1 (64.6, 69.7)	Upper-middle-income
Sri Lanka	1,136	55	40–69	51	24.4 (21.5, 27.1)	12.7	146.7 (138.0, 159.7)	42.8 (40.6, 45.0)	Lower-middle-income
St. Vincent & the Grenadines	644	53	40–69	52	29.0 (25.5, 33.4)	8.9	146.5 (137.5, 158.0)	41.6 (37.1, 46.0)	Upper-middle-income
Sudan	1,505	50	40–69	50	25.5 (22.1, 29.7)	8.4	148.3 (139.7, 160.7)	50.2 (47.6, 52.8)	Lower-middle-income
Tanzania	1,053	50	40–64	53	23.7 (20.4, 27.3)	18.4	153.5 (143.0, 169.5)	38.2 (34.9, 41.5)	Low-income
Timor-Leste	357	52	40–69	55	21.5 (19.3, 24.3)	30.5	151.0 (140.5, 162.0)	36.6 (33.4, 39.7)	Lower-middle-income
Togo	392	50	40–64	55	23.7 (21.0, 28.1)	11.3	148.0 (140.5, 161.5)	39.5 (36.0, 43.0)	Low-income
Uganda	392	51	40–69	56	22.2 (20.0, 26.0)	11.2	146.5 (136.5, 162.0)	38.8 (35.2, 42.4)	Low-income
Vanuatu	890	51	40–64	52	27.5 (24.3, 31.2)	16.8	151.0 (143.5, 164.0)	40.8 (37.6, 44.0)	Lower-middle-income
Zambia	381	51	40–69	50	24.7 (21.5, 28.9)	13.3	147.0 (140.3, 159.0)	32.7 (29.2, 36.1)	Lower-middle-income

[a]Unweighted sample size. [b]Among entire country sample. Note: Table shows weighted distribution of CVD risk factors in participants ages 40–80 years living with hypertension from population-based surveys conducted in 44 low- and middle-income countries.

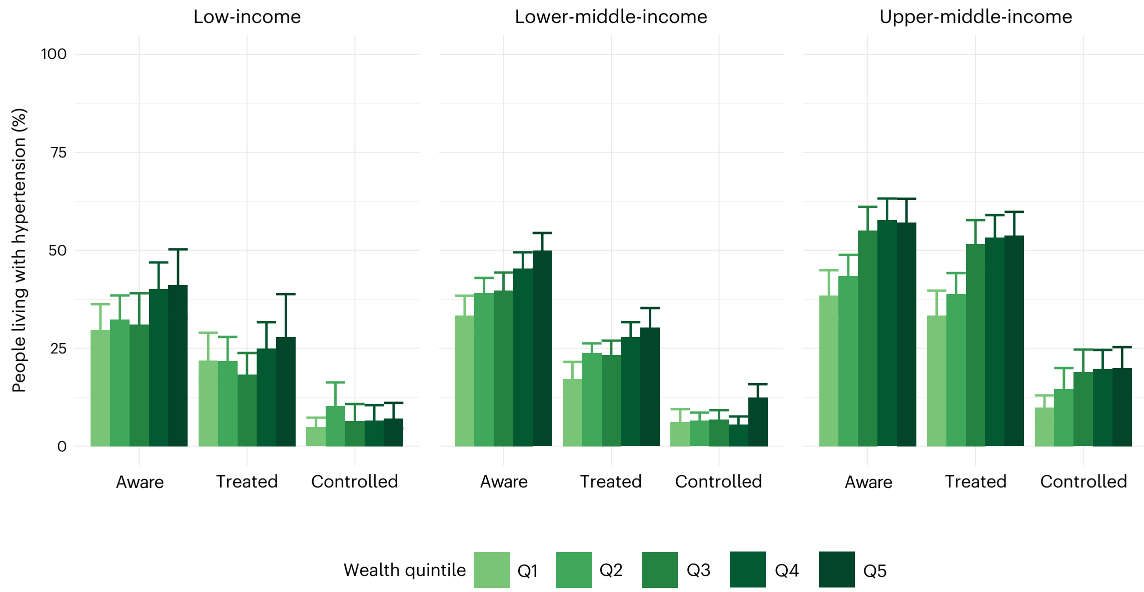

Fig. 1 | Hypertension care cascades by wealth quintile across country-level income groups. Bars represent the proportion of people living with hypertension aware of their diagnosis, on treatment and with controlled blood pressure by wealth quintile pooled across low-income ($n = 11$ countries), lower-middle-income ($n = 21$ countries) and upper-middle-income ($n = 12$ countries) country groups. Thin bars represent 95% confidence intervals.

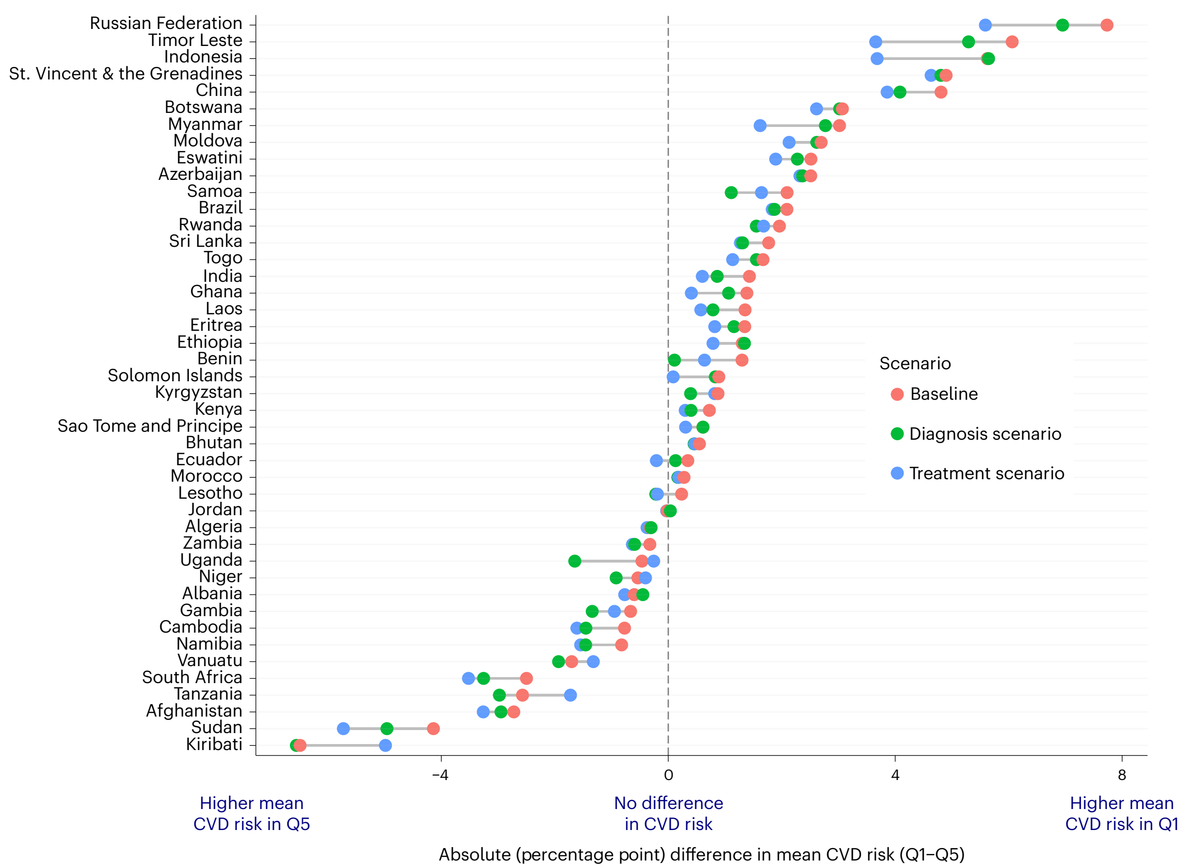

Fig. 2 | Absolute difference in mean CVD risk comparing bottom and top wealth quintiles by country and scenario. Dots represent the absolute (percentage point) difference in mean 10-year CVD risk comparing the bottom (Q1) and top (Q5) wealth quintiles, color-coded by scenario ('baseline', 'diagnosis' or 'treatment' scenario) for each country. The vertical gray dotted line at $x = 0$ represents the point where there is no difference in CVD risk comparing bottom (Q1) and top (Q5) wealth quintiles. Values to the right of the dotted line are where mean CVD risk is higher in the bottom (Q1) quintile and values to the left of the dotted line are where mean CVD risk is higher in the top (Q5) quintile. The 'baseline' scenario summarizes CVD risk by wealth quintile using the observed risk factors in each country-specific survey. In the simulated 'diagnosis' scenario, hypertension diagnosis was increased for all wealth quintiles to the level of the best-performing country quintile and maintained baseline linkage to treatment for each wealth quintile. In the simulated 'treatment' scenario, treatment coverage was increased for all wealth quintiles to the level of the best-performing country quintile across all countries.

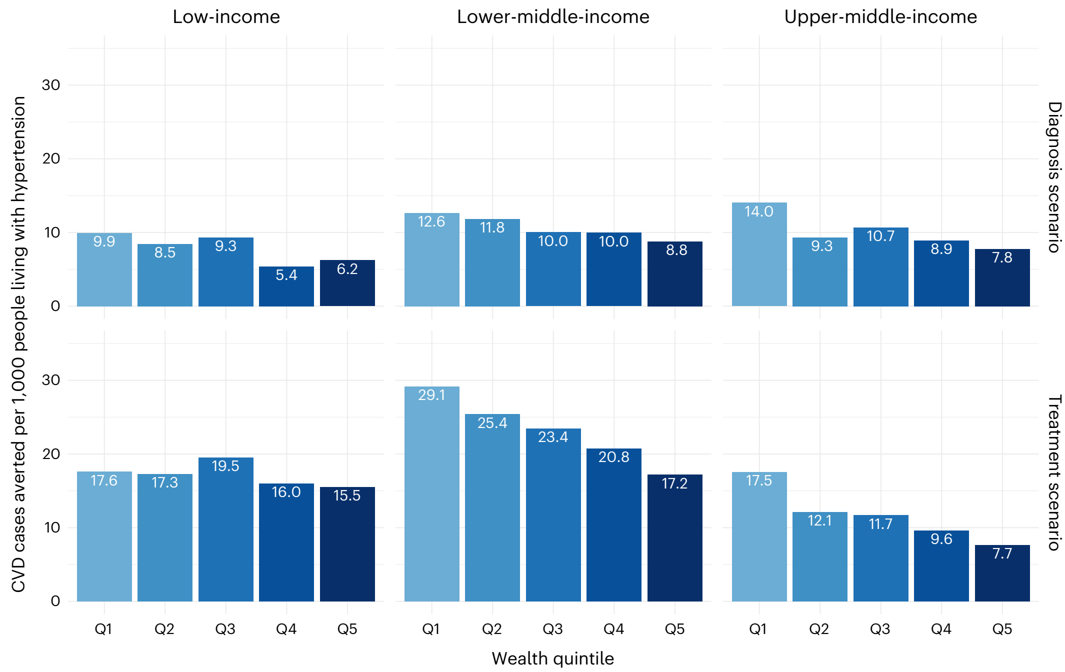

Fig. 3 | CVD cases averted compared to baseline across wealth quintiles, by scenario and country-level income group. Bars represent CVD cases averted per 1,000 people living with hypertension compared to baseline in each wealth quintile, by modeled scenario (either 'diagnosis' or 'treatment' scenario) and country-level income group. In the simulated 'diagnosis' scenario, hypertension diagnosis was increased for all wealth quintiles to the level of the best-performing country quintile and maintained baseline linkage to treatment for each wealth quintile. In the simulated 'treatment' scenario, treatment coverage was increased for all wealth quintiles to the level of the best-performing country quintile across all countries.

Distribution of CVD cases averted by country income group

Across countries, CVD cases averted were the largest among Q1 in LMICs in the treatment scenario (29.1 cases averted per 1,000 people living with hypertension) (Fig. 3). More CVD cases were averted (per 1,000 people with hypertension) among bottom quintiles compared to top quintiles across all country groups in the diagnosis scenario and among LMICs and UMICs in the treatment scenario (with the treatment scenario exhibiting a steeper gradient compared to the diagnosis scenario). A more equal distribution of CVD cases was averted across quintiles in LICs in the treatment scenario.

A greater proportion of total CVD cases averted occurred in Q1 compared to Q5 for UMICs in the diagnosis and treatment scenarios (32.0% of total CVD cases averted occurred in Q1 compared to 11.9% in Q5 in the treatment scenario, and 29.7% of cases averted occurred in Q1 compared to 14.0% in Q5 in the diagnosis scenario) (Fig. 4). For LICs, 26.8% of total CVD cases were averted among Q1 and 17.7% among Q5 in the diagnosis scenario. A more equal spread of total CVD cases averted occurred in LICs in the treatment scenario and in LMICs in both scenarios.

Distribution of CVD cases averted by cascade gap and region

Countries with large gaps in cascade performance (comparing Q1 and Q5) at baseline tended to see greater absolute benefits accruing to lower wealth quintiles compared to countries with smaller gaps in baseline cascade performance. Almost equal gains accrued to all quintiles for countries with a low gap in baseline performance for hypertension management between Q1 and Q5 (Supplementary Tables 14 and 15). Across regions, countries in Southeast Asia averted the most CVD cases per 1,000 people with hypertension among Q1 (30.4 versus 17.6 in Q5), followed by countries in Europe with 21.3 CVD cases averted per 1,000 people with hypertension among Q1 (versus 2.1 in Q5) in the treatment scenario. In terms of the proportion of total CVD cases averted, 46.9% were averted among Q1 (versus 3.2% in Q5) in countries in Europe (Supplementary Tables 16 and 17).

Sensitivity analyses

The overall magnitude and distribution of benefits depended on the target definition in the simulated intervention scenarios. When targets were set separately by terciles of baseline care cascade performance (performance-based targets), with less ambitious targets for countries with poor baseline performance, fewer CVD cases were averted (compared to the main targets). Despite smaller overall benefits, increases in diagnosis and treatment conferred larger benefits to lower wealth quintiles across all three terciles of baseline care cascade performance and across both diagnosis and treatment scenarios (measured as CVD cases averted per 1,000 people with hypertension and as proportion of total CVD cases averted; Extended Data Fig. 2 and Supplementary Tables 18–21).

When targets were set as a 50% relative improvement applied to each country quintile's baseline performance (relative increase targets), fewer CVD cases were averted (compared to the main targets), and we did not observe an equity-enhancing distribution of CVD cases averted (Extended Data Fig. 3 and Supplementary Tables 22–25). Because equal relative improvements produce larger absolute improvements for country quintiles with better baseline performance, relative increase targets did not reduce gaps in CVD risk between Q1 and Q5 and, instead, increased the gap in most countries (Extended Data Fig. 4).

When we simulated improvements to the level of the best-performing quintile within each country (within-country targets), we obtained lower absolute reductions in CVD risk across all country quintiles compared to the main targets. However, improving performance of only the worst-performing quintiles within countries led to a greater proportion of CVD cases averted among bottom quintiles in LICs, LMICs, and UMICs in the diagnosis scenario (compared to the main targets) and among LMICs and UMICs in the treatment scenario (compared to the main targets) (Extended Data Fig. 5 and Supplementary Tables 26–29).

Lastly, we observed generally weak correlation between educational attainment and wealth quintile within countries. Correlation

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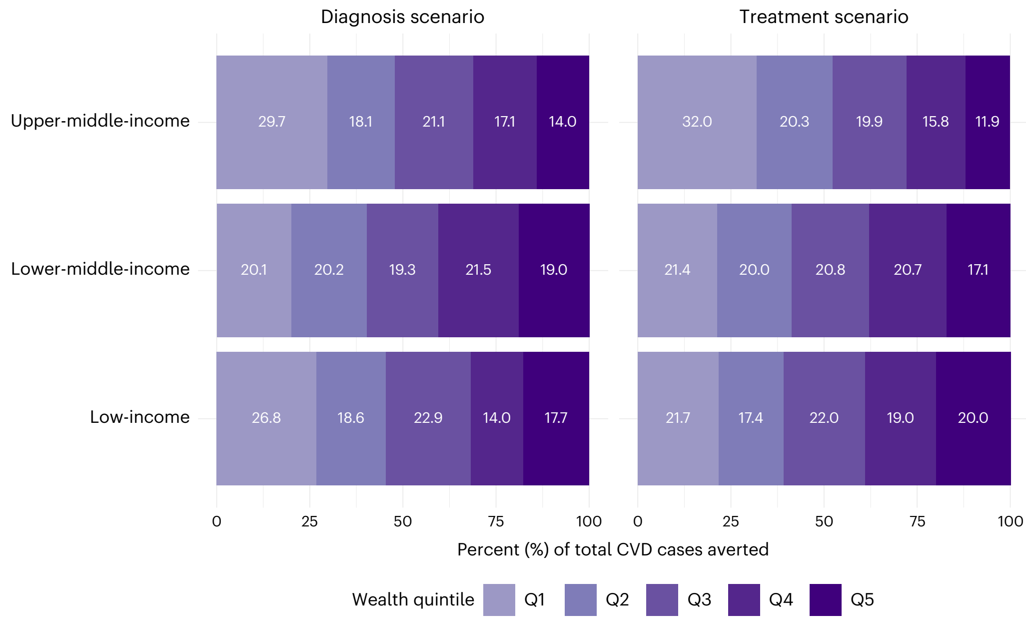

Fig. 4 | Percent of total CVD cases averted compared to baseline across wealth quintiles, by scenario and country-level income group. Bars represent the percent of total estimated CVD cases averted compared to baseline in each wealth quintile across country-level income groups and modeled scenario (either 'diagnosis' or 'treatment' scenario). In the simulated 'diagnosis' scenario, hypertension diagnosis was increased for all wealth quintiles to the level of the best-performing country quintile and maintained baseline linkage to treatment for each wealth quintile. In the simulated 'treatment' scenario, treatment coverage was increased for all wealth quintiles to the level of the best-performing country quintile across all countries.

coefficients were between 0.0 and 0.3 in 15 countries, between 0.3 and 0.5 in 23 countries and greater than 0.5 in only six countries. Higher educational attainment tended to be associated with better outcomes across the hypertension care cascade in LICs and LMICs; however, this pattern was not observed in UMICs (Supplementary Table 30). In both diagnosis and treatment scenarios in the education group targets, larger benefits generally accrued to populations with lower education in LICs and LMICs, whereas benefits were more evenly distributed in UMICs (Supplementary Table 31).

Discussion

Simulating individual-level data from 44 nationally representative surveys, we found that the largest benefits accrued to bottom quintiles in LMICs in the treatment scenario (when defined as CVD cases averted per 1,000 people with hypertension) and in UMICs in both scenarios (proportion of total CVD cases averted), with LICs seeing relatively equal benefits accrued across quintiles in the treatment scenario and a slight pro-poor gradient in the diagnosis scenario. This may be due to LMICs and UMICs being relatively farther along in the demographic, epidemiological and nutritional transitions compared to LICs. As countries develop, fertility declines, populations age and dietary patterns change, chronic disease burden tends to shift from predominantly impacting wealthier, urban populations to lower-income, rural populations[40–43].

The population-level impact of improved treatment coverage was higher compared to improved diagnosis without improved linkage to treatment (approximately 7.0 million versus 4.5 million CVD cases averted). Absolute benefits also tended to be larger for the bottom quintiles in the treatment scenario compared to the diagnosis scenario where inequalities in linkage to treatment across quintiles remained at baseline levels. Countries where the loss from diagnosis to treatment was lower (which was more common in UMICs) could reach equity-enhancing CVD outcomes by improving diagnosis levels and maintaining baseline linkage to treatment; however, countries where that loss was higher and more unequal (more common in LMICs) should focus on improving diagnosis levels across wealth quintiles and improving linkage to treatment among poorer-performing quintiles. Among LICs, priorities should include improving diagnosis, linkage to treatment and subsequently treatment coverage levels across quintiles, because coverage for all cascade steps was low. These findings highlight that equitable improvements in diagnosis must be coupled with improving equity in linkage to treatment. Understanding how treatment programs (such as the World Health Organization's (WHO) HEARTS hypertension package) can be tailored to consider disparities in diagnosis and treatment coverage across socioeconomic groups within countries will be critical for executing equity-sensitive hypertension management[44].

Expectedly, countries with large performance gaps in managing the hypertension care cascade across wealth quintiles tended to have greater reductions in CVD risk among the bottom quintiles compared to countries with smaller baseline performance gaps. Targeted interventions that improve hypertension diagnosis and treatment coverage gaps between top and bottom quintiles could, thus, substantially improve health among the poorest. On the demand side, health financing policies that reduce financial barriers to accessing care for hypertension, including medical consultations and access to medicines, could incentivize utilization among the poorest while also improving financial risk protection[8,16,45,46]. This may include interventions such as conditional cash transfers for accessing and being retained in care or expansion of universal coverage policies that explicitly finance primary care consultations and medicines costs for chronic disease care and risk factor management. Improving quality of primary care may also generate demand at lower health system levels and promote equitable coverage. On the supply side, community-based hypertension screening programs with integrated care teams that provide preventive care to hard-to-reach populations, such as in Costa Rica, could be an effective model for scaling up targeted interventions[47]. Task-sharing hypertension screening to community health workers can also be an effective strategy in resource-limited settings[48,49]. Tools like the HEARTS costing tool can be used by countries to assess the incremental costs of scaling up task-sharing of hypertension management[50]. Countries will need to design context-specific solutions to improve equity in coverage, especially when large performance gaps between top and bottom quintiles exist. Improved hypertension management must also be accompanied by broader health system strengthening efforts that address the determinants of poor performance, such as inadequate physical, human and financial resources, as well as suboptimal coordination of care processes and delivery of cost-effective interventions.

The sensitivity analyses highlight the importance of implementing hypertension cascade performance improvements that reach equal absolute coverage levels across wealth quintiles. Overall, varying targets according to baseline performance level tercile (performance-based targets) or to the level of the best-performing quintile within countries (within-country targets) changed the magnitude of CVD cases averted but did not substantially change the distribution of cases averted across quintiles (compared to the main targets). The relative increase targets, however, increased CVD risk disparities. This represents a situation where hypertension management is implemented in a way that is agnostic to addressing socioeconomic-based disparities in hypertension diagnosis and treatment levels. Simply improving average coverage levels for hypertension diagnosis and treatment may further exacerbate socioeconomic-based inequalities in CVD risk, again highlighting the need for equity-sensitive hypertension management policies to implement targeted interventions aimed at reaching equal (and improved) coverage levels across socioeconomic groups. Although there was low correlation between educational attainment and wealth quintile, improving performance for hypertension management also resulted in equitable improvements in CVD risk across education levels, particularly in LICs and LMICs.

We have shown that, by improving diagnosis and treatment of hypertension, health systems can reduce CVD risk disparities across socioeconomic groups. The distribution of benefits, however, will ultimately depend on baseline differences in health status and intervention coverage across quintiles. Examining the distribution of CVD risk factors and care cascade performance by socioeconomic groups is important for evaluating whether health system strengthening interventions can contribute to gains in both levels and distributions of health within countries.

This study has several limitations and assumptions. First, CVD risk scores were estimated over a 10-year horizon, and so we did not consider lifetime benefits of improved hypertension management, which may underestimate impact. We chose a 10-year time horizon because the CVD risk calculators calibrated to LMICs estimate risk over 10 years. Within the 10-year horizon, we assumed that individuals initiated on treatment would adhere to treatment, which may overestimate the effect of improved treatment coverage. We also did not account for prior CVD events when calculating individual-level CVD risk due to limited availability of data, and we were unable to use laboratory-based Globorisk models due to limited data on lipid levels and diabetes status[51]. As a result, we assumed that BP control among people living with diabetes and hypertension would be similar to those living with only hypertension[52]. We also chose to use Globorisk risk prediction models because Globorisk provides 10-year CVD risk scores calibrated at the country level, whereas WHO risk charts, for example, are calibrated only at the regional level[51,53,54]. Second, this analysis simulated impact among one cohort representing the population, including its age structure, in each country quintile at the time of the survey. We did not simulate the impact of cascade improvements over multiple cohorts over time for which changing population demographics and trends in CVD risk factor prevalence would need to be considered. In terms of cascade data, we used cross-sections of cascade performance, but longitudinal data on changes in performance for diagnosis, treatment and control would likely provide a more realistic picture of an individual's progression through the hypertension care cascade over time[55]. Third, because we conducted a complete case analysis that removed observations for which any relevant variable was missing, we assumed that any missing response was missing due to random chance and not dependent on observed or unobserved covariates[56]. In addition, some of the included surveys were older and so might not reflect current hypertension cascade performance and risk factor levels.

Fourth, the analysis did not consider the capacity of each country's health system to reach the targets but was rather meant to show the possible benefits per given target. In the diagnosis scenario, we assumed the same linkage to treatment levels as observed at baseline; however, undiagnosed individuals are likely more difficult to link to treatment compared to those already diagnosed. How countries can best work to improve hypertension management performance and target improvements to address equity in each cascade step will require context-specific solutions. Fifth, there is likely measurement error on the wealth quintile variable across countries. STEPwise approach to Surveillance (STEPS) surveys include only a crude, self-reported income measure (whereas other surveys, such as Demographic and Health Surveys, include a more detailed measurement of assets and wealth). Potential measurement error on the wealth variable may flatten disparities across quintiles, and our simulated equity impact of cascade improvements might be more pronounced with a more reliable wealth measure. Sixth, in terms of scope, the analysis focused only on improving diagnosis and pharmacological treatment for hypertension and did not include other interventions that could also reduce population-level CVD risk (for example, sodium reduction policies or taxes on tobacco). We also only evaluated the effect of cascade improvements on CVDs and did not consider other health benefits from increased interactions with the health system. Additionally, the inclusion of costs and cost-effectiveness is largely left for future work. Seventh, for simplicity, we chose an egalitarian norm in considering equality across wealth quintiles in our simulated scenarios, but other normative views could have been used, such as prioritarianism, for example, that would give greater weight to the worse-off[57]. Lastly, we acknowledge that our study focused only on disparities in hypertension management across socioeconomic groups and did not consider disparities across other dimensions, such as gender, ethnicity or residence, nor any interactions across these dimensions.

Globally, calls for improving health system performance for managing hypertension are increasing; however, previous projections of the health impact focus on average effects and do not consider within-country inequalities in hypertension management. In this analysis, we highlight the considerable disparities in hypertension management across socioeconomic groups within countries and show that reaching improved and equal coverage of diagnosis and treatment of hypertension can have a major impact on CVD risk equity. As equity in access and outcomes is a paramount priority for countries along their journeys toward universal health coverage, and as the burden of hypertension and CVDs continues to rise, implementing targeted interventions that lead to equitable improvements in health system performance for managing hypertension will be critical. National health systems and the global health community will need to develop and scale up context-specific and equity-sensitive hypertension management programs along with explicitly prioritizing equity in national and international target setting for hypertension management and CVD prevention more broadly.

Online content

Any methods, additional references, Nature Portfolio reporting summaries, source data, extended data, supplementary information, acknowledgements, peer review information; details of author contributions and competing interests; and statements of data and code availability are available at https://doi.org/10.1038/s41591-023-02769-8.

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Methods

Ethics and inclusion statement

Ethical approval for the included population-based surveys was sought from the respective country's ethics review committee before data collection. All surveys followed standardized ethics procedures, such as asking for participants' informed consent to participate in the respective surveys. The final collated Global Health and Population Project on Access to Care for Cardiometabolic Diseases (HPACC) dataset is de-identified, and no investigator can contact or re-identify participants. The HPACC dataset was designated as Non-Human Subjects Research by the Harvard T.H. Chan School of Public Health under protocol IRB16-1915. Local researchers were included in the research process and are listed as authors where relevant. Local and regional research has been taken into account in citations.

Overview

We developed a microsimulation model to estimate the impact of improving socioeconomic-based equity in the hypertension care cascade on the distribution of 10-year CVD risk across wealth quintiles in 44 low- and middle-income countries. We simulated two scenarios: (1) a 'diagnosis scenario', where the proportion of people living with hypertension aware of their diagnosis in each country quintile was raised to the level of the best-performing country quintile (while maintaining baseline levels of quintile-specific linkage to treatment); and (2) a 'treatment scenario', where the proportion of people living with hypertension on treatment was raised to the level of the best-performing country quintile (Extended Data Fig. 1).

First, for each country, we estimated the baseline distribution of CVD risk using individual-level data on CVD risk factors, including age, sex, smoking status, BMI and SBP, from population-based surveys. We constructed hypertension care cascades (hereafter referred to as 'cascades') in computing, by wealth quintile, the proportion of people living with hypertension who (1) were aware that they were hypertensive, (2) were on treatment for hypertension and (3) had hypertension controlled.

Second, for each country, we simulated the impact of improving cascade performance for hypertension screening (that is, diagnosis) and treatment across wealth quintiles for two target scenarios (see 'Baseline, diagnosis and treatment scenarios' subsection below). The coverage levels of the target scenarios (for the proportion of people with hypertension to be screened and linked to treatment) were set to the best-performing wealth quintile in each cascade step ((1) and (2) above) across all countries (that is, the best-performing 'country quintile').

By scenario, we summarized the change in CVD risk across wealth quintiles and countries by calculating absolute (CVD cases averted per 1,000 people with hypertension) and relative (mean relative (%) decline in CVD risk) changes compared to baseline. We also reported CVD cases averted per 1,000 people with hypertension and the proportion of total CVD cases averted in each wealth quintile, pooled by country-level income group (following the World Bank classification), baseline cascade gap terciles (calculation described below) and WHO region[58].

Target population and data sources

We used individual-level data from WHO STEPS surveys and other similar, nationally representative surveys from 44 low- and middle-income countries conducted from 2007 to 2019. These surveys were collated and harmonized by the HPACC[59]. Details on the surveys included can be found in Supplementary Table 32.

Using a microsimulation model, we simulated improvements in cascade performance for individuals living with hypertension (defined as SBP ≥ 140 mmHg or diastolic blood pressure (DBP) ≥ 90 mmHg according to WHO guidelines)[60]. We conducted a complete case analysis among individuals aged 40–80 years. Individuals included in the analysis had non-missing responses for age, sex, BMI (height and weight), smoking status (current smoker or not) and SBP as well as information on whether they were aware that they were hypertensive or were on anti-hypertensive treatment (Supplementary Table 33). We included countries for which a measure of socioeconomic status (SES, income or asset index) was available (see below) to construct wealth quintiles within each country. We did not include countries where the bottom wealth quintile showed better hypertension care cascade outcomes compared to the top wealth quintile at baseline. All estimates were adjusted for the survey design so that findings were representative of each country's population at the time of the survey.

Measurement of BP

For individuals with three BP measurements, we used the mean of the last two measurements; for those with only two BP measurements, we averaged the measurements. In instances when no second or third measurement was taken, we used the single measurement. We defined hypertension status as either SBP ≥ 140 mmHg or DBP ≥ 90 mmHg or reporting to take medication to lower BP. Details on measurement devices, number of measurements and interval between BP measurements by survey and country are provided in Supplementary Table 34.

Construction of wealth quintiles

For the surveys providing information on household ownership of durable goods and dwelling characteristics, we used the standard approach of the Demographic and Health Surveys to compute a household wealth index. We created a binary indicator for each asset and dwelling characteristic and conducted a principal component analysis (PCA) on these variables, and then we extracted the first (unrotated) principal component from the PCA. This yielded a continuous household wealth index, which we divided into quintiles.

Most STEPS surveys asked about household income in the past year. If survey participants were not able to provide this information, they could select from a pre-coded scale of income ranges. We combined both measures into joint wealth quintiles by sorting pre-coded income categories into quintiles generated from exact responses. We estimated an income ranking within pre-coded categories using primary sampling unit, education and work status and assumed a log-normal distribution of income to determine the shares of individuals falling into each of the quintiles generated from exact responses[58]. Wealth quintile type by country is provided in Supplementary Table 35.

CVD outcomes

For each individual, we estimated the 10-year risk of CVD events (including coronary heart disease (CHD) and stroke) using office-based Globorisk models and the observed risk factors in the surveys[42].

Baseline, diagnosis and treatment scenarios

We modeled improvements in horizontal equity (those with the same needs receive the same amount of care) along the hypertension care cascade. This contrasts with vertical equity, where individuals with different levels of need consume different amounts of care[61]. In our analysis, achieving horizontal equity means that the same level of hypertension diagnosis or treatment is achieved for all people living with hypertension across wealth quintiles and countries. The baseline and two simulated (diagnosis and treatment) scenarios are described immediately below.

Baseline scenario. We computed the 10-year risk of CVD events by wealth quintile in each country using the observed risk factors in the surveys.

Diagnosis scenario (simulated). We identified the best-performing country quintile in terms of the proportion of individuals with hypertension aware that they were hypertensive (that is, diagnosed), across all countries and quintiles. We then randomly assigned a subset of individuals with hypertension unaware of their status (that is, undiagnosed) in each quintile to be newly diagnosed, to raise the proportion of individuals with hypertension aware of their status to the level of the best-performing country quintile. We assumed the same linkage to treatment (that is, proportion of those diagnosed linked to treatment) observed in each country quintile's baseline cascade for the proportion of the additional individuals diagnosed initiated on treatment.

Treatment scenario (simulated). We identified the best-performing country quintile in terms of the proportion of individuals with hypertension who were on treatment, across all countries and quintiles. We then randomly assigned a subset of individuals with hypertension not on treatment to be initiated on treatment, to raise the proportion of individuals on treatment to the level of the best-performing country quintile.

Impact of anti-hypertensive medications on CVD risk

To estimate the relative risk (RR) reduction on CVD risk for each individual on treatment in the scenarios of improved diagnosis and improved treatment, we conducted a two-stage estimation[62].

First, we calculated the estimated change in SBP from one BP-lowering drug (standard dosage). Second, we used the estimated change in SBP for each individual to calculate age-specific reductions in CVD risk for CHD and stroke separately. To create a composite RR reduction estimate, we took a weighted average of each individual's estimated risk reduction for CHD and stroke. We used weights that corresponded to the proportion of CVD deaths attributable to CHD and stroke from the 2019 Global Burden of Disease study for each country, age group and sex category[63]. The equations used are displayed below.

To estimate the change in SBP from one BP-lowering drug (standard dosage) for an individual i, we used[62]:

$$\Delta SBP_i = 9.1 + 0.10 * (SBP_{pre_i} - 154), \quad (1)$$

where SBP_{pre_i} is the individual i's pre-treatment SBP.

To estimate the corresponding RR reduction, we used[62]:

$$RR_{CHD_i} = (RR_{CHD})^{\frac{\Delta SBP_i}{20}}, \quad (2)$$

where RR_{CHD} is the age-specific RR for CHD (Supplementary Table 36 and ref. 62) and:

$$RR_{St_i} = (RR_{st})^{\frac{\Delta SBP_i}{20}}, \quad (3)$$

where RR_{St} is the age-specific RR for stroke (Supplementary Table 36).

A composite RR estimate could then be computed as:

$$RR_{CVD\,i} = RR_{CHD\,i} * wt_{CHD} + RR_{St\,i} * wt_{St}, \quad (4)$$

where wt_{CHD} is the proportion of CVD deaths attributable to CHD in individual i's country, age group and sex, and wt_{stroke} is the proportion of CVD deaths attributable to stroke in individual i's country, age group and sex[63].

Statistical analysis

We applied the RR reduction to baseline CVD risk scores for individuals newly initiated on treatment in the simulated scenarios. We summarized the change in CVD risk across scenarios and wealth quintiles by reporting absolute (CVD cases averted per 1,000 people with hypertension) and relative (mean relative (%) decline in CVD risk) changes compared to baseline.

Impact on CVD risk disparities. To summarize the impact on socioeconomic-based CVD risk disparities, we evaluated the percentage point gap in CVD risk comparing the bottom (Q1) and top (Q5) wealth quintiles in each scenario and country.

Distribution of CVD cases averted by country income group. We calculated CVD cases averted per 1,000 people with hypertension and the proportion of CVD cases averted by quintile across LICs, LMICs and UMICs. First, we calculated the total number of individuals with hypertension in each country quintile by multiplying country and quintile-specific hypertension prevalence by a country's total population (in the year of the country-specific survey) divided by 5 (to approximate the number of individuals in each wealth quintile). We then summed by wealth quintile, for each country-level income group and scenario, the estimated number of CVD cases averted and divided by the total number of individuals with hypertension in that country-level income group and wealth quintile to calculate quintile-specific CVD cases averted per 1,000 people living with hypertension across LICs, LMICs and UMICs.

To calculate the proportion of CVD cases averted by quintile pooled across LICs, LMICs and UMICs, we divided the estimated number of CVD cases averted by wealth quintile, country-level income group and scenario by the total cases averted in each country-level income group and scenario. As such, countries contributed to the total CVD cases averted proportionally to the size of the population of individuals with hypertension in the country.

Distribution of CVD cases averted by cascade gap and region. We also reported results by the estimated gap at baseline for hypertension management between the bottom (Q1) and top (Q5) quintiles in each country ('baseline cascade gap'). We ranked countries by the magnitude of the differential area under the cascade comparing Q1 and Q5 and split them into three groups: 'low', 'medium' and 'high' gaps of socioeconomic disparities in the hypertension care cascade at baseline (these three gaps were delimited by the three terciles in disparities in observed cascade performance). We calculated the distribution of CVD cases averted (per 1,000 people with hypertension and as a proportion of total CVD cases averted) by baseline cascade gap tercile using the same method described above for calculations by country-level income group. Additionally, we reported results for each scenario by WHO region.

Uncertainty. We included uncertainty in the simulations due to the random selection of individuals diagnosed and/or initiated on treatment by repeating each target scenario n_1 = 1,000 times. In each iteration, we constructed distributions of our outcome measures (CVD risk and absolute and relative change in CVD risk compared to baseline) using a normal distribution with the country-specific and quintile-specific mean and standard deviation (using sampling weights and considering the clustered survey design). We then randomly sampled n_2 = 1,000 from these distributions to yield n = 1,000,000 simulated mean outcome measures. We report 95% uncertainty intervals (UIs) based on the 2.5th and 97.5th percentiles of these n estimates for each country, wealth quintile, scenario and outcome measure.

Sensitivity analyses. Our main targets used the best-performing country quintile at each cascade step as the target coverage level for all countries and quintiles. As alternatives, we tested varying targets (described below) to contrast with our main targets.

Performance-based targets. We set targets according to baseline cascade performance terciles. For this, we calculated the area under the care cascade for each quintile in each country and created terciles (bottom, middle and top) from rankings of each country's area under the cascade for its best-performing quintile. We used the best-performing country quintile within each tercile of performance as targets. The top tercile's performance-based targets are the same as the main analysis targets, whereas the middle and bottom terciles' targets are lower. These performance-based targets may be viewed as more realistic targets, especially for countries in the bottom tercile of baseline performance.

Relative increase targets. We modeled a situation where every quintile's baseline cascade performance was improved by 50% to approximate a situation where relative cascade performance improvement is equal across quintiles (rather than reaching equal absolute coverage levels). This could capture a situation where equity-sensitive cascade improvements are not implemented.

Within-country targets. We simulated here an alternative scenario where all quintiles were raised to the coverage level of the best-performing quintile within each country. This approximates a lower bound for the CVD risk reduction and distributional gains from improved hypertension management.

Education group targets. We repeated here the main analysis using level of educational attainment (no primary schooling, less than primary school completed, primary school completed, less than secondary school completed and secondary school completed), in place of wealth quintile, for the SES measure.

All analyses were conducted using R software (https://www.r-project.org/) (version RStudio 2021.09.2+382).

Reporting summary

Further information on research design is available in the Nature Portfolio Reporting Summary linked to this article.

Data availability

Many surveys contained in the HPACC dataset are publicly available. The two most common repository sources are the WHO data repository (https://extranet.who.int/ncdsmicrodata/index.php/home) and the DHS website (https://dhsprogram.com/data/). Several additional surveys have been obtained through formal requests of survey teams whose data are not publicly available. The pooled, harmonized, de-identified participant-level HPACC dataset and accompanying data dictionary have been created through a partnership among Harvard University, the University of Göttingen and Heidelberg University, in collaboration with all country-level survey teams. Access can be requested by contacting the HPACC team. More information about HPACC, including contact information for the collaboration and processes for requesting data, can be found at https://www.hpaccproject.org/.

Code availability

Replication code is available on GitHub (https://github.com/dorittalia/CVD-Equity-HPACC.git).

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Author contributions

D.T.S. and S.V. conceived the study. D.T.S. and M.B.R. performed data analysis. D.T.S. and S.V. wrote the initial draft of the paper, with input from M.B.R., R.A., P.G., J.M.-G., N.S., J.I.D., D.F., M.T. and T.B. All authors had access to the data. D.T.S. and M.B.R. have accessed and verified the data. All co-authors read and reviewed the final paper and agreed with the decision to submit the paper for publication.

Competing interests

R.A. reports consulting and speaking engagements for Merck & Co., Novartis and F. Hoffmann-La Roche unrelated to this study or the subject. He also reports grants to his institution from Novo Nordisk, Roche, Novartis and the Union for International Cancer Control for work unrelated to this study. The remaining authors declare no competing interests.

Additional information

Extended data is available for this paper at https://doi.org/10.1038/s41591-023-02769-8.

Supplementary information The online version contains supplementary material available at https://doi.org/10.1038/s41591-023-02769-8.

Correspondence and requests for materials should be addressed to Stéphane Verguet.

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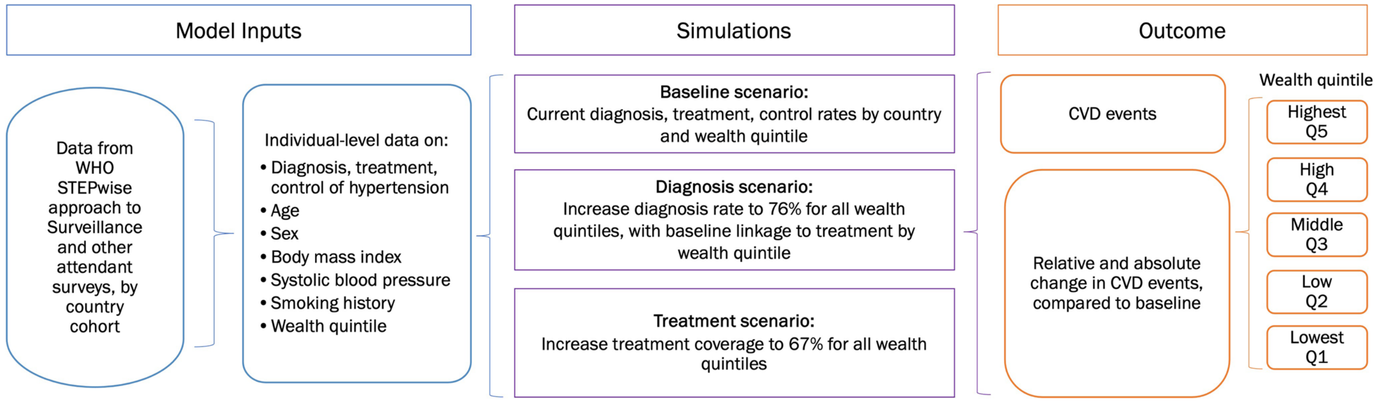
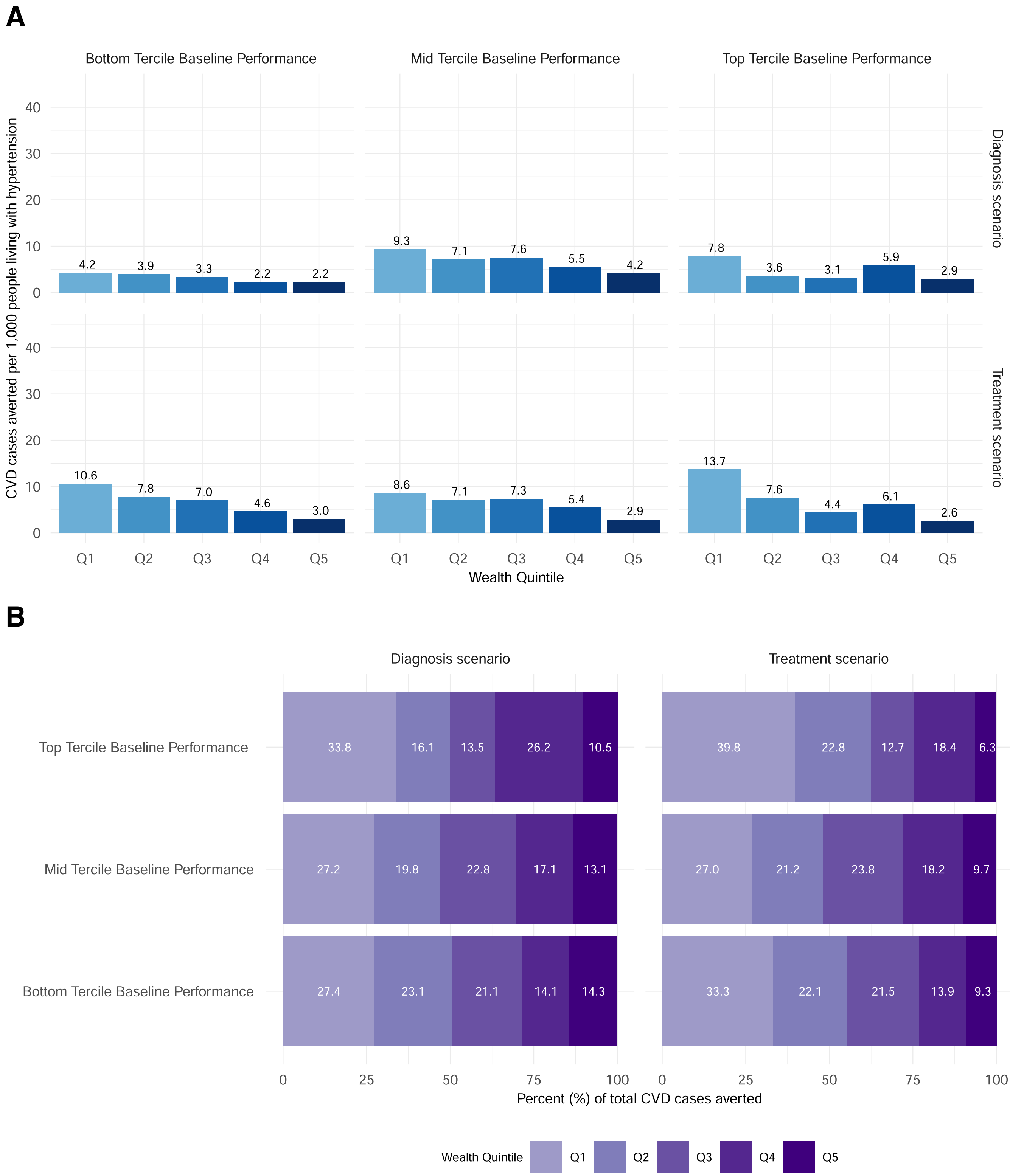
https://doi.org/10.1038/s41591-023-02769-8



Extended Data Fig. 1 | Diagram describing the main steps undertaken in the modeling analysis. Individual-level data from survey respondents living with hypertension in the WHO STEPwise approach to Surveillance and attendant surveys (2007–2019) were used to estimate baseline 10-year cardiovascular disease risk. Effect sizes from a meta-analysis were then used to estimate the effect of improvements in diagnosis and treatment rates. Targets for improved diagnosis and treatment rates in each scenario were set at the level of the best-performing wealth quintile across all countries. Relative and absolute changes in cardiovascular disease events compared to baseline were summarized by scenario, country, and wealth quintile. CVD = cardiovascular disease.



Extended Data Fig. 2 | Performance-based target results. Results from sensitivity analysis where scenario targets were set separately by terciles (top, mid, bottom) of baseline care cascade performance. **A**) Cardiovascular disease cases averted per 1,000 people living with hypertension compared to baseline across wealth quintiles, by modelled scenario (either 'diagnosis' or 'treatment' scenario) and baseline performance tercile. **B**) Percent of total estimated cardiovascular disease cases averted compared to baseline across wealth quintiles, by modelled scenario (either 'diagnosis' or 'treatment' scenario) and baseline performance tercile.

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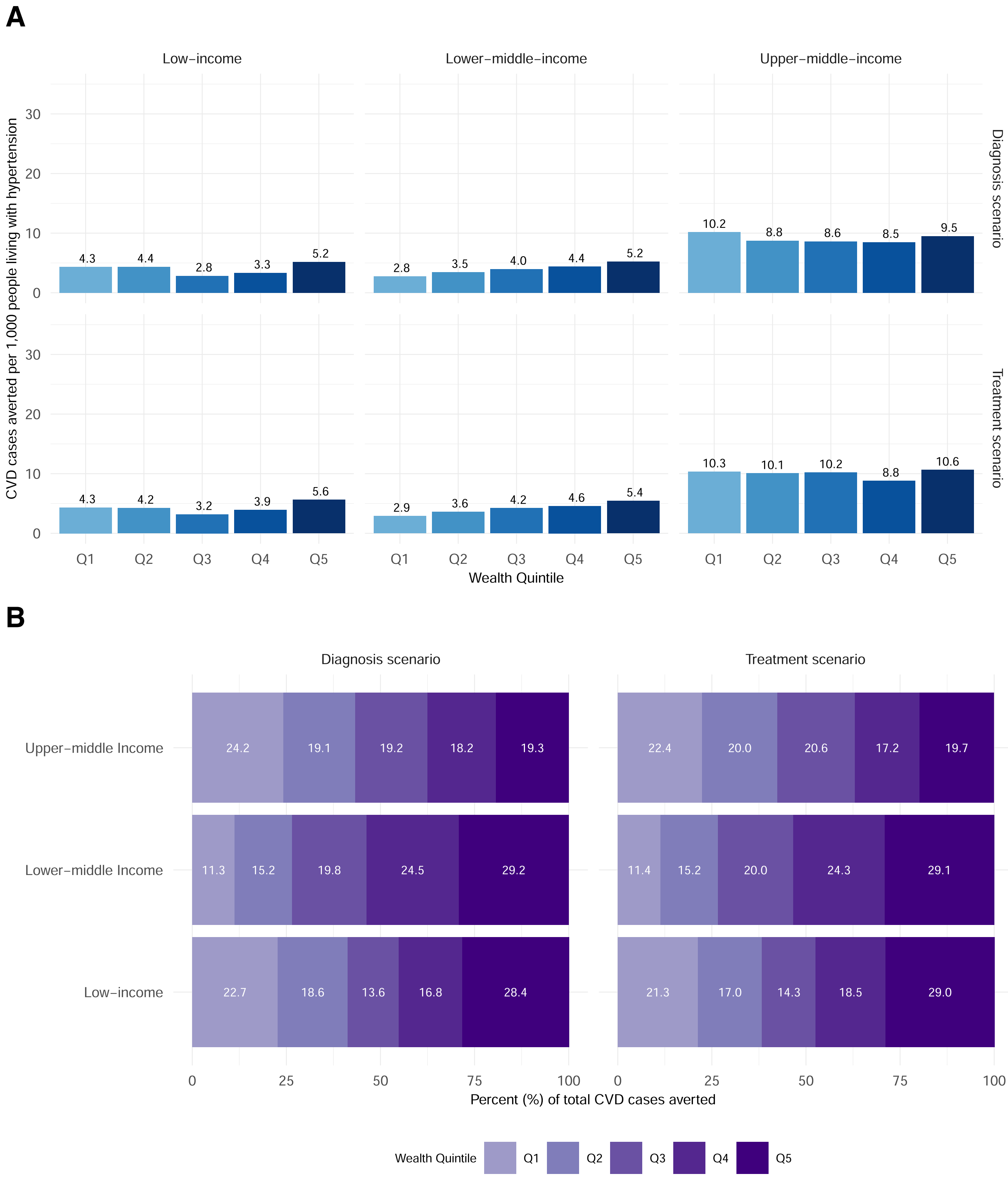
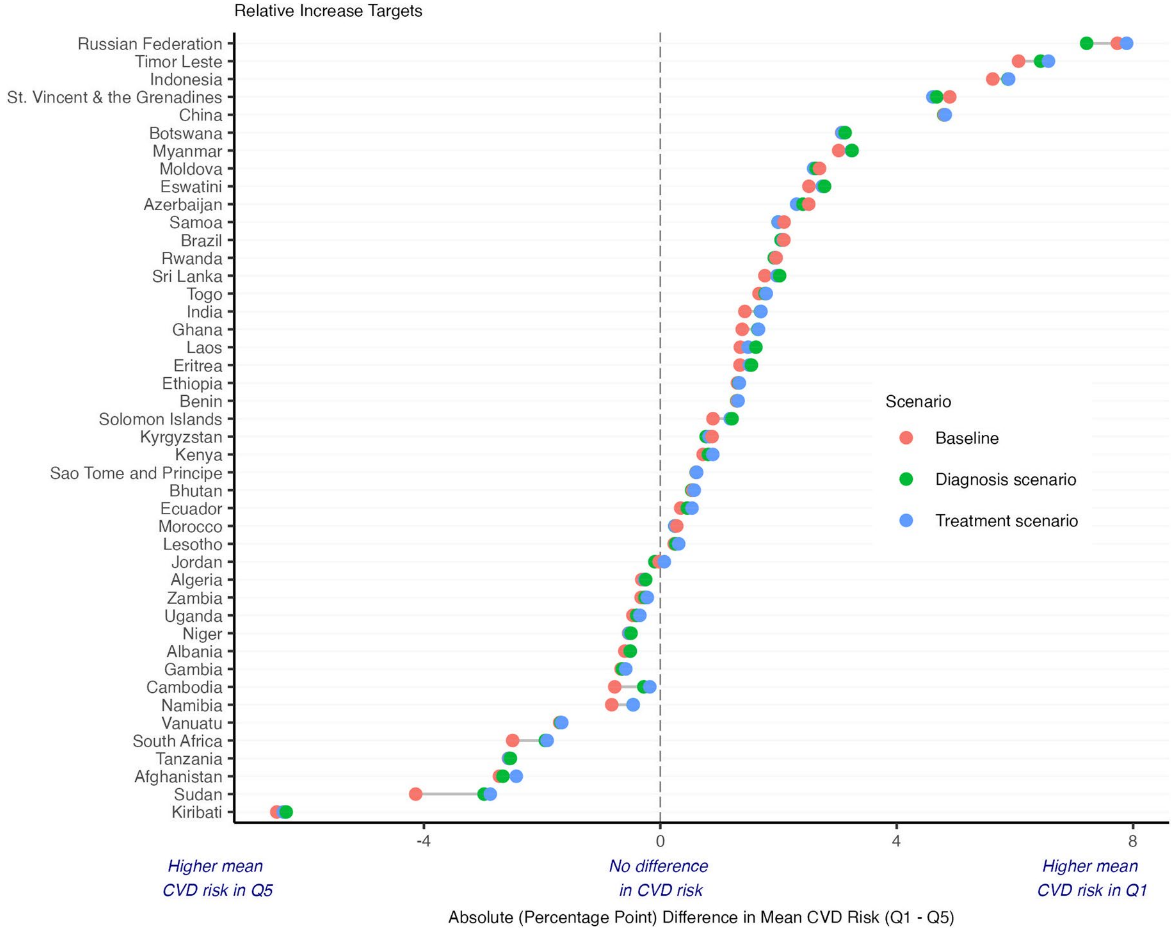
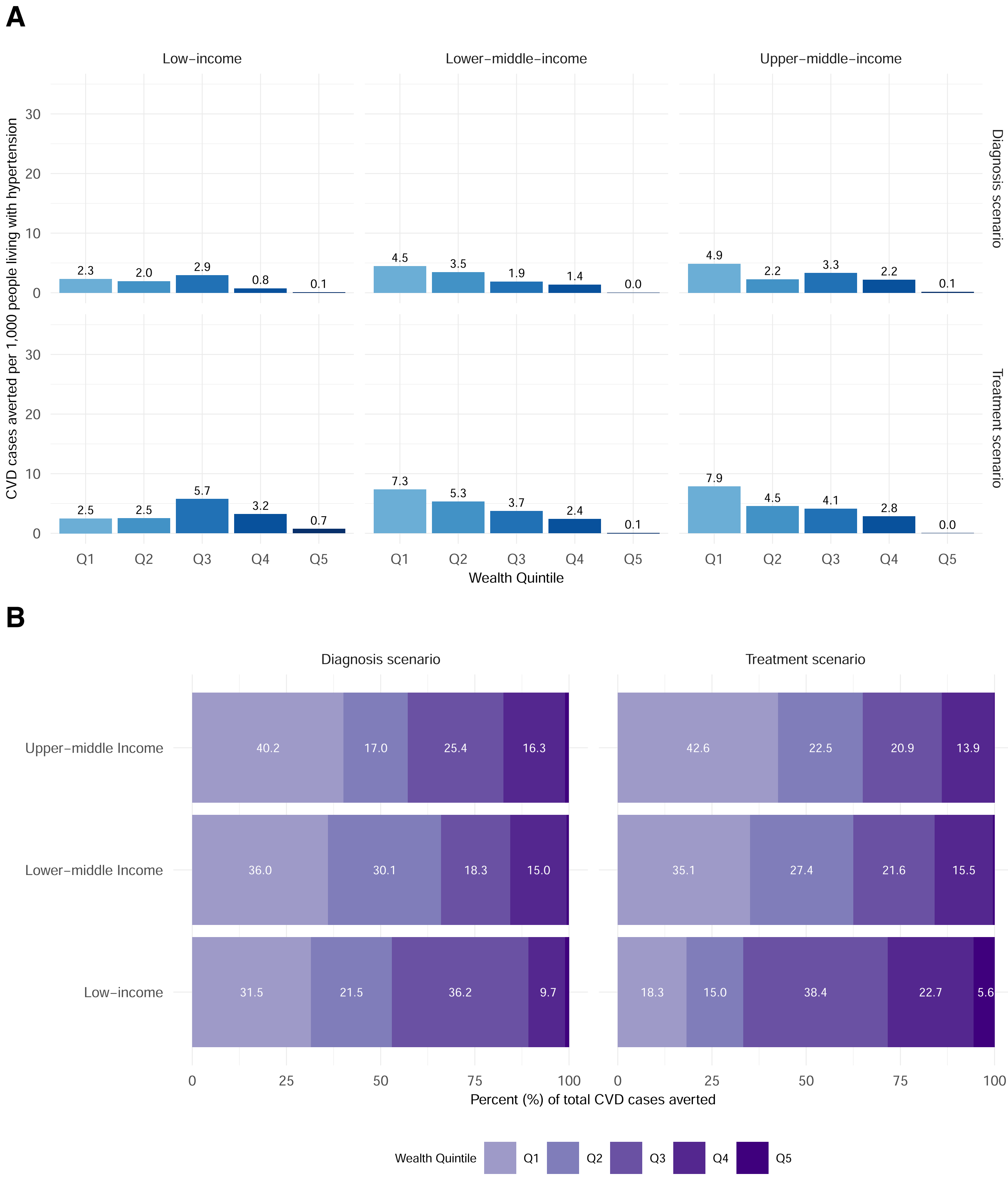


Extended Data Fig. 3 | Relative increase target results. Results from sensitivity analysis where scenario targets were set as a 50% relative improvement applied to each country quintile's baseline cascade performance. **A**) Cardiovascular disease cases averted per 1,000 people living with hypertension compared to baseline across wealth quintiles, by modelled scenario (either 'diagnosis' or 'treatment' scenario) and country-level income group. **B**) Percent of total estimated cardiovascular disease cases averted compared to baseline across wealth quintiles, by modelled scenario (either 'diagnosis' or 'treatment' scenario) and country-level income group.

https://doi.org/10.1038/s41591-023-02769-8



Extended Data Fig. 4 | Absolute difference in mean cardiovascular disease risk comparing bottom and top wealth quintiles by country and scenario for relative increase targets. Dots represent the absolute (percentage point) difference in mean 10-year cardiovascular disease (CVD) risk comparing the bottom (Q1) and top (Q5) wealth quintiles, color-coded by scenario ('baseline', 'diagnosis' or 'treatment' scenario) for each country. The vertical gray dotted line at x = 0 represents the point where there is no difference in CVD risk comparing bottom (Q1) and top (Q5) wealth quintiles. Values to the right of the dotted line are where mean CVD risk is higher in the bottom (Q1) quintile and values to the left of the dotted line are where mean CVD risk is higher in the top (Q5) quintile.



Extended Data Fig. 5 | Within-country target results. Results from sensitivity analysis where scenario targets were set to the level of the best-performing wealth quintile within each country. **A**) Cardiovascular disease cases averted per 1,000 people living with hypertension compared to baseline across wealth quintiles, by modelled scenario (either 'diagnosis' or 'treatment' scenario) and country-level income group. **B**) Percent of total estimated cardiovascular disease cases averted compared to baseline across wealth quintiles, by modelled scenario (either 'diagnosis' or 'treatment' scenario) and country-level income group.

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☒	☐	For Bayesian analysis, information on the choice of priors and Markov chain Monte Carlo settings
☒	☐	For hierarchical and complex designs, identification of the appropriate level for tests and full reporting of outcomes
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Our web collection on statistics for biologists contains articles on many of the points above.

Software and code

Policy information about availability of computer code

Data collection	No software was used.
Data analysis	R software (www.r-project.org) (version RStudio 2021.09.2+382). Replication code is available on GitHub [https://github.com/dorittalia/CVD-Equity-HPACC.git]

For manuscripts utilizing custom algorithms or software that are central to the research but not yet described in published literature, software must be made available to editors and reviewers. We strongly encourage code deposition in a community repository (e.g. GitHub). See the Nature Portfolio guidelines for submitting code & software for further information.

Data

Policy information about availability of data

All manuscripts must include a data availability statement. This statement should provide the following information, where applicable:

- Accession codes, unique identifiers, or web links for publicly available datasets
- A description of any restrictions on data availability
- For clinical datasets or third party data, please ensure that the statement adheres to our policy

Many surveys contained in the HPACC dataset are publicly available. The two most common data sources are the WHO data repository (https://extranet.who.int/ncdsmicrodata/index.php/home) and the DHS website (https://dhsprogram.com/data/). Several additional surveys have been obtained through formal requests of survey teams whose data is not already made public. The pooled, harmonised, deidentified participant-level HPACC dataset and accompanying data dictionary have been created through a partnership between Harvard University, University of Göttingen, and Heidelberg University in collaboration with all country-level survey teams. Access can be requested by contacting the HPACC team. More information about HPACC including contact information for the collaboration and processes for requesting data can be found on https://www.hpaccproject.org/.

Research involving human participants, their data, or biological material

Policy information about studies with human participants or human data. See also policy information about sex, gender (identity/presentation), and sexual orientation and race, ethnicity and racism.

Reporting on sex and gender	Sex was included as a predictor of cardiovascular disease risk in the risk prediction calculators used in this study. Results are not disaggregated by sex, however, since the focus of the paper was on socioeconomic-based inequities, results are disaggregated mainly by socioeconomic status in this analysis.
Reporting on race, ethnicity, or other socially relevant groupings	Socially relevant categorization variables used in the manuscript include an indicator of socioeconomic status, defined as wealth quintiles within each country. The wealth quintile construction is based off self-reported income or asset measures (differing depending on the country and survey) and the HPACC research team constructed the wealth quintiles from these self-reported asset or income measures taken from the country-specific surveys. Details of the wealth quintile variable construction for each country are included in the webappendix materials.
Population characteristics	"See above."
Recruitment	Please refer to survey-specific documentation for participant recruitment. This secondary data analysis did not recruit study participants.
Ethics oversight	Ethical approval for the included population-based surveys was sought from the respective country's ethics review committee before data collection. The final collated HPACC dataset was designated as Non-Human Subjects Research by the Harvard T H Chan School of Public Health in 2018 under protocol IRB16-1915.

Note that full information on the approval of the study protocol must also be provided in the manuscript.

Field-specific reporting

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Behavioural & social sciences study design

All studies must disclose on these points even when the disclosure is negative.

Study description	Data are quantitative. The analysis uses a microsimulation modeling study design.
Research sample	The research uses existing datasets from 44 countries. Many surveys contained in the HPACC dataset are publicly available. The two most common data sources are the WHO data repository (https://extranet.who.int/ncdsmicrodata/index.php/home) and the DHS website (https://dhsprogram.com/data/). The study sample includes individuals aged 40 and up (age range varies by country) which is the relevant age range for cardiovascular disease risk prediction calculators. Samples are nationally representative. More detail on survey methodology by country, including links to survey documentation, can be found in supplementary table 32.
Sampling strategy	Sampling of survey participants was conducted outside of this study as part of the original data collection conducted by each country-specific survey. Most surveys employed a random sampling design, either two-stage and/or clustered, to be nationally representative of each country at the time of the survey. In this study, we included data from participants meeting our study inclusion criteria (see 'data exclusions' below).
Data collection	This secondary modeling analysis did not do any primary data collection. Detail on survey specific data collection can be found in the documentation of each country-specific survey included in the harmonized dataset used in this study. As this was a modeling study, blinding of researchers was not applicable.
Timing	Surveys used in the analysis were collected from 2006 to 2018. Modeling analysis in this paper was conducted between 2021 and 2023.
Data exclusions	We conducted a complete case analysis among our dataset which included 100,874 individuals living with hypertension for which we had non-missing data on age, sex, BMI, smoking status, systolic blood pressure, wealth quintile, and hypertension care cascade variables. Numbers (percent) of excluded observations by country and variable can be found in supplementary table 33.
Non-participation	No participants were involved in the current study. Please refer to country-specific survey documentation for information on non-participation.
Randomization	Participants were not allocated into experimental groups.

Reporting for specific materials, systems and methods

We require information from authors about some types of materials, experimental systems and methods used in many studies. Here, indicate whether each material, system or method listed is relevant to your study. If you are not sure if a list item applies to your research, read the appropriate section before selecting a response.

Materials & experimental systems

n/a	Involved in the study
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☒	☐ Eukaryotic cell lines
☒	☐ Palaeontology and archaeology
☒	☐ Animals and other organisms
☒	☐ Clinical data
☒	☐ Dual use research of concern
☒	☐ Plants

Methods

n/a	Involved in the study
☒	☐ ChIP-seq
☒	☐ Flow cytometry
☒	☐ MRI-based neuroimaging