Budget impact and cost-effectiveness analyses of the COBRA-BPS multicomponent hypertension management programme in rural communities in Bangladesh, Pakistan, and Sri Lanka

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Summary

Background **COBRA-BPS (Control of Blood Pressure and Risk Attenuation-Bangladesh, Pakistan, Sri Lanka), a multicomponent hypertension management programme that is led by community health workers, has been shown to be efficacious at reducing systolic blood pressure in rural communities in Bangladesh, Pakistan, and Sri Lanka. In this study, we aimed to assess the budget required to scale up the programme and the incremental cost-effectiveness ratios.**

Methods **In a cluster-randomised trial of COBRA-BPS, individuals aged 40 years or older with hypertension who lived in 30 rural communities in Bangladesh, Pakistan, and Sri Lanka were deemed eligible for inclusion. Costs were quantified prospectively at baseline and during 2 years of the trial. All costs, including labour, rental, materials and supplies, and contracted services were recorded, stratified by programme activity. Incremental costs of scaling up COBRA-BPS to all eligible adults in areas covered by community health workers were estimated from the health ministry (public payer) perspective.**

Findings **Between April 1, 2016, and Feb 28, 2017, 11 510 individuals were screened and 2645 were enrolled and included in the study. Participants were examined between May 8, 2016, and March 31, 2019. The first-year per-participant costs for COBRA-BPS were US$10·65 for Bangladesh, $10·25 for Pakistan, and $6·42 for Sri Lanka. Per-capita costs were $0·63 for Bangladesh, $0·29 for Pakistan, and $1·03 for Sri Lanka. Incremental cost-effectiveness ratios were $3430 for Bangladesh, $2270 for Pakistan, and $4080 for Sri Lanka, per cardiovascular disability-adjusted life year averted, which showed COBRA-BPS to be cost-effective in all three countries relative to the WHO-CHOICE threshold of three times gross domestic product per capita in each country. Using this threshold, the cost-effectiveness acceptability curves predicted that the probability of COBRA-BPS being cost-effective is 79·3% in Bangladesh, 85·2% in Pakistan, and 99·8% in Sri Lanka.**

Interpretation **The low cost of scale-up and the cost-effectiveness of COBRA-BPS suggest that this programme is a viable strategy for responding to the growing cardiovascular disease epidemic in rural communities in low-income and middle-income countries where community health workers are present, and that it should qualify as a priority intervention across rural settings in south Asia and in other countries with similar demographics and health systems to those examined in this study.**

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Introduction

Cardiovascular diseases are the leading cause of death worldwide.[1] Cardiovascular diseases are particularly lethal in rural areas in low-income and middle-income countries where health systems are weakest and the case fatality rates of cardiovascular diseases are highest.[2–5] Addressing this burden requires low-cost, scalable interventions that target prevention and treatment of hypertension, and other cardiovascular disease risk factors.[6–9]

In 2020, we reported the efficacy of a cluster-randomised controlled trial, Control of Blood Pressure and Risk Attenuation-Bangladesh, Pakistan, Sri Lanka (COBRA-BPS), in rural communities in three south-Asian countries (Bangladesh, Pakistan, and Sri Lanka).[10] We showed that this contextually relevant, multi-component intervention delivered by community health workers (CHWs) was efficacious at reducing systolic blood pressure.[10] At 24-month follow-up, the decline in systolic blood pressure across the three countries

See Online for appendix

Research in context

Evidence before this study

The biomedical and health economics literature was reviewed to identify studies in which the burden of hypertension and cardiovascular diseases and economic evaluation of interventions was reported, particularly from low-income and middle-income countries. PubMed and Google Scholar databases were searched for studies or abstracts published in English between Jan 1, 1970, and April 20, 2020, using the search terms "cost-effectiveness", "blood pressure", "low-income countries", "middle-income countries", "hypertension", and "south Asia". The relevant full-text articles were selected and searched for further information and material. Although there have been budget impact and cost-effectiveness analyses on hypertension trials with interventions led by community health workers in low-income and middle-income countries, most of these trials focused on urban areas or on a single country. The lack of evidence from rural areas in multiple countries with differing health systems thus presents a barrier for broad implementation.

Added value of this study

To our knowledge, this study is the first budget impact and cost-effectiveness analysis on a scalable, community-based, multicomponent intervention that is led by community health workers in rural communities across three countries, namely Bangladesh, Pakistan, and Sri Lanka. We show that, compared with existing care, the Control of Blood Pressure and Risk Attenuation-Bangladesh, Pakistan, Sri Lanka (COBRA-BPS) programme is a cost-effective and scalable solution for controlling blood pressure among individuals with hypertension in rural areas in the three countries. The first-year per-participant costs for scaling up COBRA-BPS were US$10·65 for Bangladesh, $10·25 for Pakistan, and $6·42 for Sri Lanka. Per-capita costs (total costs divided by total national population count) were $0·63 for Bangladesh, $0·29 for Pakistan, and $1·03 for Sri Lanka. Incremental cost-effectiveness ratios were $3430 for Bangladesh, $2270 for Pakistan, and $4080 for Sri Lanka per disability-adjusted life-year averted.

Implications of all the available evidence

Our findings underscore that the COBRA-BPS multicomponent intervention presents a viable strategy to respond to the growing cardiovascular disease epidemic in low-income and middle-income countries and should qualify as a priority intervention.

was 5·2 (95% CI 3·2–7·1) mm Hg greater in the COBRA-BPS cluster than in control clusters, with consistent effects within each country.

In the present study, we report the budget impact analysis and cost-effectiveness of a national scale-up to rural areas within each country where CHWs are present. The budget impact analysis allows policy makers to budget the immediate and future costs should COBRA-BPS be scaled up beyond the trial communities. The cost-effectiveness analysis facilitates the comparison of COBRA-BPS with other interventions and helps to establish whether the programme represents good value for money.

Methods

Study design and participants

We did a cluster-randomised controlled trial in 30 rural communities in Bangladesh, Pakistan, and Sri Lanka. These 30 communities were randomly assigned to receive either COBRA-BPS or usual care, stratified by country (ten clusters each) and distance from the government clinic (near [≤2 km] or far [>2 km]). Individuals aged 40 years or older with hypertension were eligible for inclusion in the study. The primary and secondary outcome results of that cluster-randomised trial were reported in 2020.[10]

Ethics approval for the study was obtained from the institutional review boards of the National University of Singapore, the Interventions Research Ethics Committee of the London School of Hygiene & Tropical Medicine, and institutions of each participating country (the International Centre for Diarrhoeal Disease Research in Bangladesh, the Aga Khan University in Pakistan, and the University of Kelaniya in Sri Lanka).

Multicomponent intervention

COBRA-BPS was comprised of the following five components: (1) home health education by government CHWs, (2) blood pressure monitoring and referral, (3) training of public and private providers in management of hypertension, (4) designated hypertension triage counter and care coordinators in government clinics, and (5) a financing model to compensate for additional services equivalent to 20% of the salary of CHWs. The money was channelled through the district health office and offered the flexibility to hire additional staff or expand the role of existing staff but with the expectation that COBRA-BPS would not compromise delivery of existing services. Travel subsidies were allocated to low-income participants via means testing.

Usual care

Usual care comprised of existing community services, with CHWs routinely visiting homes for maternal and child care only. The clinics did not have hypertension-related triage counters or care coordinators.

Screening, recruitment, and follow-up

Trained research staff visited all households in the study clusters and obtained written informed consent from adults aged 40 years or older,[15] who were then screened for eligibility. Follow-up was done with home visits every 6 months for up to 2 years from baseline. Details of our delivery approach and outcomes are available in the study protocol and publication of results.[10,11]

Costs, assumptions, and budget impact analysis

We quantified all costs relating to components of COBRA-BPS, namely: (1) administration and oversight, (2) training of CHWs in blood pressure monitoring and home health education, (3) training of general practitioners, (4) implementation of home-based blood pressure monitoring and home health education, (5) coordination at hypertension triage counters, (6) medical visits (including travel subsidies and costs for additional medications), and (7) coordinating activities of CHWs' supervisors. Data that captured all costs of labour, rental, materials and supplies, and contracted services incurred by these health-care services were collected prospectively during the trial. The cost components for each activity are detailed in the appendix (pp 4, 5). All costs tracking approaches and conversions are also described in the appendix (pp 5, 6).

Both the cost-effectiveness analysis and budget impact analysis assumed that COBRA-BPS would be scaled up with existing CHWs, and that the programme would be able to reach all rural households within the first year of the scale-up. For the budget impact analysis, we estimated the incremental cost of scaling up COBRA-BPS to all eligible adults aged 40 years or older in areas where CHWs are present (100% of the rural communities in Bangladesh and Sri Lanka and 60% of the rural communities in Pakistan) from the health ministry (public sector) perspective. Costs for the budget impact analysis are presented for the first 3 years of the scale-up on the basis of recommended practices.[12–14] For the cost-effectiveness analysis, consistent with how decisions are made by many countries,[15] we estimated the lifetime incremental cost from the health system perspective, including both public and private sector costs.

Within-trial differences in health-care utilisation were estimated as for the primary effectiveness analysis using self-reported utilisation data captured from participants at baseline and at 24 months. Results of the utilisation analysis (as seen in the appendix pp 11, 12) revealed that the only consistent (across sites) and significant difference resulting from COBRA-BPS concerned greater use of antihypertensive medications in the COBRA-BPS group than the usual care group. Therefore, these costs are included in the cost-effectiveness analysis. They are not included in the budget impact analysis for Bangladesh or Pakistan because the public sector does not pay for antihypertension medications in these countries. In Sri Lanka, COBRA-BPS data show that 63% of all clinic visits at follow-up occurred at government facilities; therefore, we assume that 63% of antihypertension medication costs are paid by the government. When forecasting future costs, we assume a medication adherence rate of 75% that is maintained until death.[16]

Quantifying total costs for the budget impact analysis requires estimating both unit costs and the number of people expected to receive COBRA-BPS. To estimate the number expected to receive COBRA-BPS in year 1 of scale-up from the baseline, we multiplied estimates of the rural population aged 40 years or older in each country[17] by estimates of hypertension prevalence obtained during screening visits within our trial sites. In subsequent years, cases were quantified on the basis of an estimated hypertension incidence rate of 8·26%, assuming an annual national population growth of 1·0% in Bangladesh, 2·0% in Pakistan, and 1·1% in Sri Lanka.[17,18] Additional details of our cost estimation approach, including the source data and assumptions used to generate the cost estimates, are presented in the appendix (pp 5, 6).

Cost-effectiveness analysis

The cost-effectiveness analysis is done over a lifetime as benefits of COBRA-BPS are expected to last indefinitely, but the analysis is limited to the cohort of people with hypertension identified at baseline. The numerator of the cost-effectiveness ratio is the incremental net cost in the first year of scale-up plus the present value of costs in subsequent years discounted at 3% per annum.[19]

For the cost-effectiveness analysis, the primary measure was prespecified as the cost per projected disability-adjusted life-year (DALY) due to cardiovascular diseases that have been averted. Previous literature shows a linear association between blood pressure reduction and percentage reduction in mortality risk due to coronary heart disease, stroke, and cardiovascular diseases, and reveals that a sustained reduction of 10 mm Hg in systolic blood pressure results in a roughly 22% reduction in coronary heart disease events and a 41% reduction in stroke events and mortality.[20] On the basis of these statistics, we followed a model presented in previous literature,[21,22] and conservatively assumed that every 1 mm Hg reduction in systolic blood pressure translates into a 2·2% reduction in cardiovascular disease DALYs and assumed that participants maintain the blood pressure reductions throughout their lifetime.

Converting the percentage reduction in DALYs into absolute values of cardiovascular disease DALYs requires estimating how many cardiovascular disease DALYs would occur in the absence of COBRA-BPS. The national level of cardiovascular disease DALYs was obtained from the Global Burden of Disease 2017 and adjusted by the percentage of the population that resides in rural areas.[1,17] This value was then multiplied by the percentage reduction in cardiovascular disease DALYs conferred by COBRA-BPS, to estimate the total cardiovascular disease DALY reduction.

To account for uncertainty in our assumptions on the underlying cost distribution or the exact association

	COBRA-BPS component*	Bangladesh (US$)†	Pakistan (US$)†	Sri Lanka (US$)†
Administration and oversight	1–5	$0·08	$0·49	$0·20
Training and implementation				
Training of community health workers (standardised blood pressure monitoring and home health education)	1, 2	$4·61	$5·58	$0·33
Training of general practitioners	3	$0·12	$0·17	$0·07
Community health workers travel to households	1, 2	NA	NA	$0·27‡
Standardised blood pressure monitoring by community health workers	2	$3·06	$2·42	$1·18
Home health education	2	$2·74	$1·52	$2·59
Coordination at hypertension triage counter	4	$0·04	$0·08	$0·03
Provision of medication subsidies	5	NA	NA	$1·75
First-year cost per participant	NA	$10·65	$10·25	$6·42

NA=not applicable. *The numbered COBRA-BPS components are: (1) home health education by community health workers, (2) blood pressure monitoring and stepped-up referral to a trained general practitioner using a checklist, (3) training of public and private providers in management of hypertension and using a checklist, (4) designated hypertension triage reception and hypertension care coordinators in government clinics, and (5) a financing model to compensate for additional health services and provide subsidies to individuals with a low income and poorly controlled hypertension. More details can be found in the appendix (pp 5,6). †First-year costs per participant (reported as 2020 US$) were calculated by dividing total costs for the activity in the first year by the number of eligible participants with hypertension. ‡Stipend was given as a travel voucher for community health workers.

Table 1: **First-year costs per participant by activity**

between systolic blood pressure reductions and DALY improvements, we report scenario analyses focusing on three crucial parameters. These parameters are: (1) the highest incremental cost per capita, (2) lowest mean reductions of systolic blood pressure, and (3) lowest percentage reduction in DALYs per unit reduction in systolic blood pressure for which COBRA-BPS would remain cost-effective in each country, based on the common threshold of three times gross domestic product (GDP) per capita. We then present cost-effectiveness acceptability curves for each country, which we generated using TreeAge Pro 2019. These curves show the percentage of 1000 iterations[23] that exceed a given willingness-to-pay threshold that governments might consider as cost-effective when costs and the association between systolic blood pressure reductions and DALY improvements are fixed at the base-case levels and when the incremental improvement in systolic blood pressure follows a normal distribution with mean and variance as estimated in the effectiveness analysis. Results of mean systolic blood pressure reductions are shown in the appendix (p 13). Lastly, we explore the implications of moving from a 3% to a 6% discount rate for costs.[19] Consistent with current recommendations, DALYs are not discounted.[24]

Role of the funding source

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

Results

Between April 1, 2016, and Feb 28, 2017, 11 510 individuals were screened and 2645 were enrolled and included in the study. Participants were examined between May 8, 2016, and March 31, 2019. We estimated that 9·67 million individuals in Bangladesh, 5·62 million individuals in Pakistan, and 3·43 million individuals in Sri Lanka would be expected to screen positive for hypertension (appendix p 13). On the basis of these counts, 7·71 million (33%) of 23·47 million rural households in Bangladesh, 3·84 million (35%) of 11·05 million rural households in Pakistan, and 2·14 million (46%) of 4·61 million rural households in Sri Lanka would have at least one adult with hypertension and therefore receive home health education in year 1 of the scale-up (appendix p 13).

Table 1 presents the per-participant costs by cost category for the budget impact analysis. Per-participant costs were estimated to be US$10·65 for Bangladesh, $10·25 for Pakistan, and $6·42 for Sri Lanka.

Table 2 presents the per-participant (all rural people with hypertension aged 40 years or older) and per-capita (of national population) costs, eligible population counts, and total budget impact by country for the first 3 years of implementation; costs by activity are presented in the appendix (pp 6, 7). Cost estimation methodologies in first and subsequent years of scale-up can also be found in the appendix (pp 5, 6). In year 1 of scale-up, total budgetary impact costs are estimated to be $103·0 million in Bangladesh, $57·6 million in Pakistan, and $22·0 million in Sri Lanka to reach 9·67 million, 5·62 million, and 3·43 million rural individuals with hypertension aged 40 years or older, respectively. Based on national populations, per-capita costs are estimated to be $0·63 in Bangladesh, $0·29 in Pakistan, and $1·03 in Sri Lanka (table 2). Recurring per-participant costs in year 2 of scale-up are estimated to be $6·52 for Bangladesh, $5·70 for Pakistan, and $6·03 for Sri Lanka, and in year 3 of scale-up are estimated to be $6·05 for Bagladesh, $5·13 in Pakistan, and $5·92 in Sri Lanka. From year 1 to year 2 of scale-up, estimated costs (total budget impact) reduced by 28% in Bangladesh and by 33% in Pakistan, whereas estimated costs increased by 3% in Sri Lanka; from year 1 to year 3 of scale-up, estimated costs reduced by 24% in Bangladesh and by 31% in Pakistan, whereas costs increased by 10% in Sri Lanka. For years 2 and 3, estimated per-participant and per-capita costs decreased in Bangladesh and Pakistan mainly because of reduced training frequencies, as only refresher trainings were required. For Sri Lanka, although estimated training costs also decreased, an increase in the cost of medication subsidies led to a slight increase in total cost.

In our cost-effectiveness analysis, the mean age of participants in the trial was 57 years in Bangladesh and Pakistan and 63 years in Sri Lanka.[10] Based on conditional life expectancies, participants are expected to live an average of 24 additional years in Bangladesh, 22 additional years in Pakistan, and 21 additional years in Sri Lanka.[25] The discounted present value of future intervention delivery costs for these durations was added to first-year costs to calculate the mean incremental cost. The health-care utilisation analysis (appendix pp 11, 12) reveals an overall increase in mean number of monthly antihypertensive medications of 0·11 (95% CI 0·04–0·18) at final follow-up (24 months after baseline), prompting us to assume that there is an increased use of antihypertensive medications. Although we did consider other differences in health-care costs (appendix pp 11, 12), we found no other significant differences in costs between treatment and control groups, and therefore other costs were excluded from the analysis.

Using a methodical cost estimation of market prices of antihypertensive medicines in each country (as described in the appendix [pp 5, 6]), the per-participant lifetime incremental cost of scaling up COBRA-BPS was estimated to be $147 in Bangladesh, $136 in Pakistan, and $110 in Sri Lanka (appendix p 9). Based on the incremental costs (appendix p 8), the percentage of lifetime costs attributable to increased use of anti-hypertensive medication is 16% ($221·29 million of $1·42 billion) in Bangladesh, 22% ($165·20 million of $766·33 million) in Pakistan, and 40% ($151·35 million of $377·97 million) in Sri Lanka, with differences driven by differential medication use rates and prices across countries.

The primary effectiveness analysis found that systolic blood pressure in rural communities decreased by a mean of 4·39 mm Hg (95% CI 7·84–0·94) in Bangladesh, 4·99 mm Hg (9·63–0·35) in Pakistan, and 6·22 mm Hg (8·98–3·45) in Sri Lanka (table 3). Assuming that every 1 mm Hg reduction in systolic blood pressure translates into a 2·2% reduction in cardiovascular disease DALYs,[20–22] we multiplied the mean incremental reduction of systolic blood pressure in each country by 2·2% to estimate the percentage reduction in cardiovascular disease DALYs conferred by the COBRA-BPS programme.

	Year 1	Year 2	Year 3
Bangladesh (100% coverage)			
Cost per participant	$10·65	$6·52	$6·05
Cost per capita*	$0·63	$0·45	$0·47
Eligible population†	9 671 504	11 391 650	13 009 795
Total budget impact*‡	$102 993 340	$74 294 630	$78 652 010
Pakistan (60% coverage)			
Cost per participant	$10·25	$5·70	$5·13
Cost per capita*	$0·29	$0·19	$0·20
Eligible population†	5 619 670	6 728 994	7 796 449
Total budget impact‡	$57 610 060	$38 365 390	$40 021 640
Sri Lanka (100% coverage)			
Cost per participant	$6·42	$6·03	$5·92
Cost per capita*	$1·03	$1·05	$1·10
Eligible population†	3 428 737	3 763 279	4 079 978
Total budget impact‡	$22 006 890	$22 675 410	$24 140 330

Data are 2020 US$ or n. Costs are rounded to the nearest $0·01 and the total budget impacts are rounded to the nearest $10. *Cost per capita is total cost divided by total national population count. †Individuals aged 40 years or older with hypertension in rural communities. ‡A breakdown of the cost types can be found in the appendix (pp 6, 7).

Table 2: **Budget impact per participant and per capita from the health ministry perspective, in years 1–3 of implementation**

This reduced percentage of cardiovascular disease DALYs was then multiplied by cardiovascular disease DALYs borne by the eligible population to estimate the DALYs savings provided by the COBRA-BPS programme in each country. Dividing the costs by these savings yielded base-case incremental cost-effectiveness ratios of $3430 per DALY averted in Bangladesh, $2270 per DALY averted in Pakistan, and $4080 per DALY averted in Sri Lanka (table 3). Based on WHO-CHOICE thresholds of three times GDP per capita as a guide for what is cost-effective,[17,26] the base-case estimates (as seen in table 3) show COBRA-BPS to be cost-effective in all three countries.

The sensitivity analyses showed that, maintaining other parameters as constant values, COBRA-BPS would remain cost-effective at an incremental cost that was 48% higher than the base case in Bangladesh, 97% higher than the base case in Pakistan, and 202% higher than the base case in Sri Lanka (appendix p 9). COBRA-BPS would also remain cost-effective if, all else being equal, mean incremental reductions of systolic blood pressure were no lower than 2·96 mm Hg in Bangladesh, 2·54 mm Hg in Pakistan, and 2·06 mm Hg in Sri Lanka, or if the percentage improvement in DALYs for each 1 unit decrease in systolic blood pressure remained above 1·48% in Bangladesh, 1·12% in Pakistan, and 0·73% in Sri Lanka (appendix p 9). Using a 6% discount rate for costs instead of the 3% base rate,[19] the cost-effectiveness ratio would improve to $2640 in Bangladesh, $1780 in Pakistan, and $3210 in Sri Lanka (appendix p 9).

The cost-effectiveness acceptability curves that are based on the probabilistic sensitivity analyses of 1000 draws[23] from the estimated distribution for systolic

	Bangladesh (100% coverage)	Pakistan (60% coverage)	Sri Lanka (100% coverage)
Total incremental cost for cost-effectiveness analysis (US$)*	$1 421 174 180	$766 327 830	$377 973 350
Mean incremental reduction of systolic blood pressure (mm Hg)[10]	4·39 (7·84–0·94)	4·99 (9·63–0·35)	6·22 (8·98–3·45)
Cardiovascular disease DALYs borne by eligible population (n)†	4 285 514	3 082 505	676 600
Avertable cardiovascular disease DALYs (n)‡	413 895	338 397	92 586
Incremental cost per cardiovascular disease DALY averted (US$)	$3430	$2270	$4080
WHO threshold for being cost-effective (US$)§	$5090	$4450	$12 310
Gross domestic product per capita[17]	$1560	$1460	$4080

Data are n, mm Hg (95% CI), or 2020 US$. Monetary values are rounded to the nearest $10. DALY=disability-adjusted life-year. *A breakdown of the cost types can be found in the appendix (p 8). †Individuals aged 40 years or older with hypertension in rural communities. ‡Based on an estimated 2·2% reduction in cardiovascular disease DALYs per 1 mm Hg reduction in systolic blood pressure. §Threshold for being cost-effective set for at least three times gross domestic product per capita of each country.[17,26]

Table 3: **Cost-effectiveness of COBRA-BPS from the health systems perspective**

blood pressure improvements, maintaining all other values as fixed, are shown in the appendix (pp 9, 10). These figures present the percentage of iterations that were predicted to be cost-effective for each willingness-to-pay threshold that decision makers might consider. Applying the cost-effectiveness guidelines of WHO for Bangladesh ($5090), Pakistan ($4450), and Sri Lanka ($12 310), COBRA-BPS was predicted to be cost-effective in 79·3% of iterations in Bangladesh, 85·2% of iterations in Pakistan, and 99·8% of iterations in Sri Lanka.

Discussion

In the multinational cohort in the PURE study, which included several low-income and middle-income countries, hypertension attributed the largest risk to cardiovascular diseases and death.[27] This multi-country, cluster-randomised trial presents, to our knowledge, the first evidence that a customisable community-based intervention led by CHWs can be a cost-effective, scalable, and potentially sustainable solution for controlling blood pressure among those with hypertension in rural areas. Although countries use their own criteria for what is deemed cost-effective, COBRA-BPS was cost-effective for each of the three countries according to the WHO thresholds.

A primary reason for the cost-effectiveness of COBRA-BPS is the relatively low per-participant cost. Scaling up COBRA-BPS would cost each country's government less than $10·70 per participant in year 1, with comprehensive training being responsible for roughly half of the costs. In subsequent years, costs are expected to decrease as only refresher trainings are required for existing CHWs. However, if countries need to scale up the number of CHWs, as might be the case for Sri Lanka given the low number of CHWs per capita, then training costs would increase. Sri Lanka is also the only country where the government pays for medications, and medication subsidies are responsible for 27% of their per-participant costs.

When considering per-capita costs across the entire population of each country, as opposed to per-participant costs, the costs were estimated at less than $1 per year in Bangladesh and Pakistan, and less than $1·20 per year in Sri Lanka. Differences in costs across countries result from differences in the number of CHWs required to be trained, differences in training costs, and differences in implementation design, staffing models, wage rates, and hypertension prevalence, as greater hypertension prevalence reduces the average fixed cost of the programme by spreading it across more individuals.

Although previous hypertension trials from low-income and middle-income countries have also shown cost-effectiveness based on similar cost-effectiveness analysis thresholds,[28] COBRA-BPS is unique with its focus on rural populations, integration of all components into the existing health-care infrastructure, and reliance on government CHWs to proactively conduct blood pressure monitoring and health promotion activities. Leveraging this infrastructure contributed substantially to the low costs of programme delivery regardless of differences in programme implementation, hypertension prevalence, and underlying cost structures. Therefore, our results are likely to be generalisable to many low-income and middle-income countries that rely on CHWs.

Given our budget impact projections and current health budgets of $6·00 per capita in Bangladesh, $14·00 per capita in Pakistan, and $69·00 per capita in Sri Lanka,[17] the benefits of COBRA-BPS could be achieved with a health budget increase of 10% in Bangladesh, 3% in Pakistan, and 2% in Sri Lanka in the first year and slightly less in subsequent years in Bangladesh and Pakistan (but slightly more in Sri Lanka due to greater cost of medications). Although affordability is always a concern, these cost increases are not substantially greater than other "best buy" interventions recommend by WHO.[29]

This study has many strengths, including a standardised intervention, a rigorous multi-country effectiveness evaluation, and prospective cost data collection. Yet there are limitations. One limitation for the cost-effectiveness analyses is that the cost-effectiveness ratios are based on an algorithm that directly converts blood pressure reductions to DALYs averted. Although we use conservative assumptions for this relationship and did sensitivity analyses to measure the influence of our assumptions on results, additional studies should be done to find out whether this relationship holds over longer time periods. The analyses also assumed no differences in long-term health-care utilisation across study groups. This assumption is probably conservative as a successful intervention should result in fewer cardiovascular disease events. The analyses also assume that the benefits of blood pressure reduction and the relationship of blood pressure reduction with improvement in DALYs would continue throughout the participants' lifetime. As some of the improvements in systolic blood pressure resulted from overall increased use of medications, both our cost and cost-effectiveness estimates would be inflated if usage decreased with time. Consistent with the latest recommendations, we also did not discount DALYs.[24] Discounting DALYs would reduce the cost-effectiveness ratios to unknown degrees as the timing of future cardiovascular disease events is unknown. We also did not measure the effect of COBRA-BPS on the existing duties of CHWs, which include maternal and child health services. However, the funds for additional work were channelled through the district office in each country with the flexibility to hire additional workers if needed. Thus, we assume the benefits of COBRA-BPS did not come at the expense of other programmes. Finally, we limit the benefits of COBRA-BPS to benefits caused by reductions in blood pressure. However, our intervention, which also focuses on nutrition, tobacco cessation, and physical activity, probably has other benefits that expand beyond blood pressure improvements.

The programme could be further strengthened by including other components, such as risk factor reductions for diabetes or other chronic diseases, additional medication subsidies, or even universal health coverage, as out-of-pocket costs remain a barrier to access to medications and health services in Bangladesh, Pakistan, and Sri Lanka, as well as other countries.[2]

In summary, this study presents robust evidence for a cost-effective multicomponent programme led by CHWs, namely, COBRA-BPS, for the management of hypertension in rural communities. The programme's low cost and high scalability suggest that it presents a viable strategy for responding to the growing cardiovascular disease epidemic in rural communities in low-income and middle-income countries currently served by CHWs and should qualify as a priority intervention in the targeted countries and possibly many other countries.

Contributors

THJ conceptualised the overall design of COBRA-BPS. MG contributed to the statistical analysis plan, and EAF and AKr to the reimbursement model in the design and cost-effectiveness analysis in consultation with THJ. AN, IJ, and HAdS contributed to local adaptation in Bangladesh, Pakistan, and Sri Lanka, and contributed to the data collection together with NC, DSE, JK, AKa, SH, and AKMS. AKr, CWL, and MG did the data analysis, and EAF and THJ did the interpretation. AKr and CWL wrote the first draft with input from EAF and THJ. All authors contributed to the interim drafts and approved the final version. EAF and THJ had full access to and verified all the data. All authors had full access to all data in the study and final responsibility for the decision to submit for publication. All COBRA-BPS study group members contributed to various aspects of the study at the respective sites and in the steering committee or data monitoring and safety board.

Declaration of interests

We declare no competing interests.

Data sharing

The study protocol is publicly available.[11] Additional data can be shared on request from the corresponding authors.

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