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An analytical model of population level uncontrolled hypertension management: a care cascade approach

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Abstract

Effective control of hypertension at the population level is a global public health challenge. This study shows how improving population coverages at different hypertension care cascade levels could impact population-level hypertension management. We developed an analytical framework and a companion Excel model of multi-level hypertension care cascade entailing awareness, treatment, and control. The model estimates the prevalence of uncontrolled hypertension for different level of population coverages at certain cascade levels. We applied the model to data from Bangladesh and reported prevalence estimates associated with coverage interventions at different cascade levels. The model estimated that if 50% of the unaware hypertensive patients became aware of their hypertensive condition, the prevalence of uncontrolled hypertension would decrease by 1.8 and 1.3 percentage points (8.2% and 5.8% relative reduction), respectively, for constant and variable rates in the status quo setting. When 50% of the aware, but untreated individuals received treatment, the prevalence would decrease by around 0.7 percentage points (3.3% relative reduction). A 50% decrease in the share of treated individuals who did not have hypertension under control, would result in decreasing the prevalence by 2.8 percentage points (12.7% relative reduction). By providing an analytical tool that demonstrates the probable impact of population coverage interventions at certain hypertension care cascade levels, our study endows public health practitioners with vital information to identify gaps and design effective policies for hypertension management.

INTRODUCTION

Hypertension prevention and control are critical public health issues around the world. About 1.13 billion people worldwide have hypertension, and the majority are living in

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low-and-middle-income countries (LMICs) [1]. The prevalence of hypertension has also been rapidly increasing in LMICs over the past few decades [2]. In the United States, almost 45% (108 million) of adults have hypertension and this was a contributory cause of nearly half a million deaths in the country in 2018 [3]. The pattern is no different in the rest of the world. Only about one in four adults (24%) with hypertension have their condition under control in the United States and less than one in five people have the problem under control in LMICs [1, 3].

Globally, hypertension is a major cause of premature deaths. Raised blood pressure accounts for more than 13% of the 60 million annual deaths worldwide [4]. Given the limited capacities of the health systems and resource constraints in many LMICs, effective hypertension management at the population level is a public health challenge. The United Nations Sustainable Development Goals (SDGs) targets to reduce premature mortality from noncommunicable diseases (including hypertension) by one-third by the year 2030 [5]. The World Health Organization also sets a target to reduce the prevalence of hypertension or raised blood pressure by 25% by the year 2025 as part of its global action plan for the prevention and control of noncommunicable diseases [6], and in order to achieve these targets, it is important to understand how certain interventions would affect population level hypertension management and deliver the desired prevalence outcomes.

Effective hypertension management may be achieved at different levels of the multi-level hypertension care cascade entailing awareness, treatment, and control. In this regard, we developed a model that enables the analyses of scenarios of hypothetical interventions at each level of the hypertension care cascade. The premise of the model is that not all hypertensive individuals are aware of their hypertensive status, and not all individuals are receiving treatment among those who are aware of their status. Among those who are receiving treatment, not all have the disorder under control. In a hypothetical setting, improving the treatment effectiveness may only affect those who are currently receiving treatment, leaving behind those who are unaware of their hypertension or not receiving treatment despite knowing about their condition. Our model will facilitate the understanding of public health practitioners' and other stakeholders' about how altering the levels of lack of awareness or lack of treatment could impact population level hypertension control.

Several studies have previously examined the hypertension care cascade across countries and population sub-groups [7–12]. We build on the findings of these analyses to demonstrate how improvement in population coverage at different levels of the care cascade translates to reducing the prevalence of uncontrolled hypertension. We apply our model for Bangladesh, a LMIC with a high and rising burden of hypertension [13]. In Bangladesh, more than 14 million people aged 35 years and older are hypertensive, and only 2.65 million have their blood pressure under control [14]. Considering the large number of undiagnosed (unaware) and untreated hypertensive individuals, managing hypertension, therefore, is one of the major public health challenges in Bangladesh. To this end, our model may play a critical role in articulating effective strategies through a comprehensive understanding of the linkage to diagnosis, treatment, and control of hypertensive condition.

METHODS

Model structure

The framework for this study is illustrated in Fig. 1. There are three scenarios of uncontrolled hypertension: (1) hypertensive individuals that are unaware of their hypertensive condition; (2) those not receiving treatment; and (3) those not having the condition under control despite receiving treatment. Individuals aware of their hypertensive condition has a higher probability of receiving treatment; and hypertensive individuals receiving treatment has a higher probability of having the hypertension under control. Therefore, the likelihood of receiving treatment would increase if individuals who previously were unaware of the condition become aware of their hypertension diagnosis. Similarly, the likelihood of having hypertension under control would increase if diagnosed hypertensive individuals begin to receive treatment. If more hypertensive individuals are aware of their condition, more will likely seek treatment, and therefore more hypertensive cases will be under control.

For any population group, there is a status quo probability of awareness of diagnosed hypertension among hypertensive individuals; a status quo probability of receiving treatment among individuals that are aware of their diagnosis; and a status quo probability of having hypertension under control among treatment recipients. Status quo probabilities can be obtained from population surveys. Given the status quo probabilities associated with subsequent cascade levels, a change in the preceding cascade level would change the outcome (i.e., hypertension control) through cascading channels following the status quo probabilities.

The impact of the change at a cascade level can be different if status quo probabilities associated with subsequent cascade levels are also changed. We define an intervention as “status quo intervention” if there are no changes in status quo probabilities in subsequent cascade levels. We define an intervention as “best practice intervention” if status quo probabilities in subsequent cascade levels are set at the level of that for a better performing health system.

Model estimation

Based on the status quo hypertension prevalence, awareness (diagnosis) rate among hypertensive population, treatment rate among diagnosed individuals, and control rate among treated individuals, we estimate the baseline uncontrolled hypertension prevalence using the following equation:

$$UHTN\ PRV_{baselline} = \frac{\sum_a pop_a \times htn_a \times [1 - aware_a \times treat_a \times control_a]}{\sum_a pop_a} \times 100\% \quad (1)$$

Where, pop_a is population of age group *a*, htn_a is hypertension prevalence of age group *a*, $aware_a$ is share of hypertensive individuals of age group *a* aware of hypertensive condition, $treat_a$ is share of hypertensive and diagnosed individuals of age group *a* receiving treatment, and $control_a$ is share of hypertensive, aware, and treatment recipient individuals of age group a who have hypertension under control. The term $htn_a \times [1 - aware_a \times treat_a \times control_a$ in Eq. 1 is the uncontrolled hypertension prevalence of age group a. The population level prevalence, therefore, can be viewed as the weighted average of age-group-specific prevalence rates, where weights are population count of the respective age groups. The step-by-step derivation of Eq. 1 is provided in the supplementary information document (Supplementary Figs. S1 and S2). The uncontrolled hypertension prevalence for alternative scenarios is estimated using the following formula:

$$UHTN\ PRV_{alternative} = \frac{\sum_a pop_a \times htn_a \times [1 - (\rho \times (1 - aware_a) + aware_a) \times (\theta \times (1 - treat_a) + treat_a) \times (\lambda \times (1 - control_a) + control_a)]}{\sum_a pop_a} \times 100\% \quad (2)$$

Parameters ρ, θ, and λ can take values ranging from 0 to 1. These parameters respectively indicate the share of unaware getting aware, share of untreated receiving treatment, and share of uncontrolled having hypertension under control. If ρ equals 0 then the share of hypertensive individuals unaware of their hypertensive condition is same as that at baseline level. As the value of ρ increases, more and more hypertensive individuals become aware of their hypertensive condition. If ρ equals 1 then every hypertensive individual, previously unaware, become aware of the hypertensive condition. Similar properties apply to θ and λ for the treatment (among aware) and control (among treated), respectively.

If the values of ρ, θ, and λ are set at 0 then Eq. 2 collapses into Eq. 1 and provides the baseline estimate. The interventions in the model can be made by altering the value of ρ for intervention in awareness, the value of θ for intervention in treatment, and the value of λ for intervention in control phase of the hypertension care cascade. For intervention in awareness, a desired value of ρ is chosen and the values of θ and λ are set at 0. Similarly, for intervention in treatment, the values of ρ and λ are set to 0; and for intervention in control, the values of ρ and θ are set to 0. Interventions at multiple cascade levels can be assessed as well by simultaneously setting the values of ρ, θ, and λ at desired levels.

In Eq. 2, the treatment rate for every additional aware hypertensive individual and the control rate for every additional treated individual are constant. The treatment rate and control rate, however, may diminish as numbers of aware and treated are increased. To incorporate the changing treatment and control rate with respect to the change in number of aware and treated, we assume associated treatment and control elasticities and replace $treat_a$ and $control_a$ in Eq. 2 with following specification:

$$treat_{i,a} = \left(1 - \left(\frac{naware_{i1,a}}{naware_{i0,a}} - 1\right) \times e_{treat,a}\right) \times treat_a$$
$$s.t. 0 \le e_{treat,a} < \left(\frac{1 - \frac{ntreat_{0,a}}{ntreat_{100,a}}}{\frac{naware_{100,a}}{naware_{0,a}} - 1}\right) \quad (3)$$

$$control_{j,a} = \left(1 - \left(\frac{ntreat_{j1,a}}{ntreat_{j0,a}} - 1\right) \times e_{control,a}\right) \times control_a$$
$$s.t. 0 \le e_{control,a} < \left(\frac{1 - \frac{ncontrol_{0,a}}{ncontrol_{100,a}}}{\frac{ntreat_{100,a}}{ntreat_{0,a}} - 1}\right) \quad (4)$$

Where, *naware* is the number of aware, *ntreat* is the number of treated, and *ncontrol* is the number of controlled. The subscripts *0* and *1* refer to baseline and alternative scenarios, respectively. The subscripts *i* and *j* refer to the percentages decrease of unaware and untreated, respectively, and $i \in [0, 100]$, $j \in [0, 100]$. The treatment elasticity, $e_{treat,a}$, indicates the percentage decrease in treatment rate due to 1% increase in aware hypertensive individuals in age group *a*. Similarly, control elasticity, $e_{control,a}$, indicates the percentage decrease in control rate due to 1% increase in treated hypertensive individuals in age group *a*. Bounds on the values of the elasticities are imposed to ensure that the number of treated or the number of controlled not going below the baseline level. If $e_{treat,a}$ is 0, then the treatment rate is constant for any *i* as in Eq. 2. Similarly if $e_{control,a}$ is 0, then control rate is constant for any *j*.

As described in the model structure sub-section, the model has two versions—"status quo" version and "best practice" version. In the status quo version, the values of $treat_a$, and $control_a$ are set at the status quo level. In the best practice version users can choose different values of $treat_a$, and $control_a$ for intervention in awareness; and different values of $control_a$ for intervention in treatment. The best practice version of the model, thus, can be referred as interventions at multiple cascade levels. Each version of the model is estimated for the constant treatment and control rates (i.e., elasticity = 0) and for the variable treatment and control rates (i.e., elasticity ≠ 0).

Application

We applied the model for Bangladesh and obtained parameters from the 2018 National STEPS survey [15]. The STEPS survey is a nationally representative survey that measures respondent's systolic and diastolic blood pressure and collects hypertension history following a standardized framework developed by the World Health Organization [16]. The best practice parameters are adopted from Geldsetzer et al. [8] that reports the cascade of hypertension care in 44 LMICs. From these countries' data, we took the best treatment rate among aware, and best control rate among treated. In line with the STEPS survey, we considered four age groups—15–24, 25–39, 40–54, and 55–69. We used population count for these age groups for the year 2020 from the United Nations World Population Prospects estimates [17]. Table 1 shows the status quo and best practice parameter values for respective age groups.

We consider three scenarios of intervention at each cascade levels. For the awareness intervention, the scenarios are 50% of the unaware hypertensive individuals become aware ($\rho = 0.5$), 75% become aware ($\rho = 0.75$), and 90% become aware ($\rho = 0.9$). Similarly, for the treatment and control interventions, the values of θ and λ are set at 0.5, 0.75, and

0.9 for respective scenarios. We also present results for continuum values of ρ, θ, and λ (ranged from 0 to 100) for relative comparison of different interventions. We estimate two versions—one with 0 elasticity (i.e., constant treatment and control rate), and the other with value of elasticities set at 0.1 (i.e., variable treatment and control rate) for both status quo and best practice interventions.

Model interface

We have developed a user-friendly interface of the model in Excel which allows users (e.g., public health practitioners) to set certain policy parameters. The results are generated based on parameter selections and will allow users to compare three different policy scenarios for each cascade level. The Excel interface of the model is presented in the supplementary information document (Supplementary Figs. S3 and S4). The Excel tool is also supplied as a supplementary material.

RESULTS

The baseline prevalence of uncontrolled hypertension for age 15–69 population in Bangladesh was 22.3%. The prevalence was lower for younger age groups and gradually increased with age. Table 2 presents the results for status quo intervention. At the awareness cascade level, with constant treatment and control rates, the prevalence decreased by 1.8 percentage points (8.2% relative reduction) if 50% of the unaware hypertensive individuals became aware and decreased by 3.3 percentage points (14.8% relative reduction) if 90% of the unaware became aware of their hypertensive condition. The decrease was smaller (1.3 and 2.1 percentage points; 5.8% and 9.5% relative reduction) when variable treatment and control rates were considered. At the treatment cascade level, we observed relatively smaller improvements in hypertension control than interventions at the awareness cascade level. When 90% of the aware but untreated individuals received treatment, the prevalence of uncontrolled hypertension decreased by only 1.3 and 1.1 percentage points (6.0% and 5.1% relative reduction) respectively for constant and variable control rates. Lastly at the control cascade level, if the share of treated individuals who did not have hypertension under control decreased by 50% then the prevalence of uncontrolled hypertension decreased by 2.8 percentage points (12.7% relative reduction). A 90% decrease resulted in as high as 5.1 percentage points or 22.9% relative reduction in uncontrolled hypertension prevalence.

The best practice intervention results are presented in Table 3. We reported a best practice baseline ($\text{Baseline}_{\text{BP}}$) to demonstrate how better treatment and control rates could decrease uncontrolled hypertension prevalence without any population coverage intervention. If the best practice treatment and control rates could be implemented, then the prevalence would become 21.6 without any change in status quo awareness rate. With the best practice control rate, the prevalence would have been 21.8 without any change in status quo treatment rate. At the awareness cascade level, 90% reduction in unaware under the best practice intervention would decrease the prevalence of uncontrolled hypertension to 17.5% and 19.0% respectively (18.7% and 12.0% relative reduction) for constant and variable treatment and control rates. At the treatment cascade level, 90% reduction in untreated would decrease the prevalence to 20.2% and 20.5% respectively (5.88% and 6.06% relative reduction) for the constant and variable control rate. Different combinations of interventions (no change, 50, 75, 90, and 100% decrease) at multiple cascade levels are assessed in Supplementary Table S1.

Figure 2 shows the relative comparison of status quo and best practice interventions at different cascade levels under constant and variable rates. It also illustrates the outcome of each intervention in comparison to the WHO target of 25% relative reduction in prevalence. Standalone interventions at the awareness and treatment cascade levels cannot deliver outcomes required to achieve the 25% relative reduction target. The best practice intervention at the awareness cascade level with constant treatment and control rates delivers relatively better outcomes as prevalence rate got close to the target when awareness reached 100%. At the control level, the 25% relative reduction target could be attained with a 100% control rate, which may not be feasible given existing antihypertensive medication and treatment protocols. Overall, the model estimates suggest that the 25% relative reduction target may not be attained through a single intervention, rather interventions are required at multiple cascade levels.

DISCUSSION

This study presents a model of hypertension care cascade that highlights the needs for improvement at certain cascade levels to achieve any desired level of uncontrolled hypertension prevalence. Applying data from Bangladesh, we estimated and reported the changes in prevalence of uncontrolled hypertension that could have been achieved under planned population coverages at the aware, treatment, and control cascade levels. We developed a companion Excel model that enables figuring out the required population coverages at different care cascade levels to attain any desired level of uncontrolled hypertension prevalence. The tool allows users to choose appropriate sets of parameters that resemble health care systems of a particular country or health status of a particular population-group and provides a platform to compare outcomes of different interventions. Thus, this tool endows public health practitioners with helpful information to identify the gap and to design effective policies for population level hypertension management.

A key strength of the model is its applicability to any country, region, or population groups. The model's ability to assess uncontrolled hypertension prevalence for both standalone interventions at single cascade level and combined interventions at multiple cascade levels is another plus. Further, by allowing comparison of "status quo" and "best practice" scenarios, the model serves as an assessment tool for a country's existing hypertension management system and unveils scopes for improvement at different cascade levels.

Reducing the prevalence of raised blood pressure or hypertension is a global public health priority. Hypertension is a major risk factor of heart diseases, stroke, and other morbidities [1]. Population-level hypertension management is, therefore, closely tied with several SDG-3 targets [5]. Our model thus has direct relevance in strengthening the efforts to achieve the SDG-3 targets in the LMICs.

A limitation of the model is that it is developed under a static framework and does not explain how things will change over time. The next step will be incorporating this model to a dynamic population model and examining how interventions impact prevalence outcomes over a course of time. In addition, the model does not analyze implementation strategies of the interventions. It only analyzes the scenarios of “if” the interventions were made and evaluates how these would impact the prevalence of uncontrolled hypertension. Future research needs to explore effective strategies to implement the interventions as well as the resource need for implementing certain interventions.

CONCLUSIONS

Previous studies mostly explored the status of hypertension care cascade across different countries and population groups [7–12]. The findings of these studies provide important information about existing structure of hypertension care in a country. However, these studies do not evaluate how population coverage improvements at single and/or multiple care cascade levels are associated with hypertension control outcomes. This gap in the literature was addressed in this study by providing an analytical framework and a companion tool that demonstrates the probable impact of interventions at certain cascade levels on the prevalence of uncontrolled hypertension. Our analysis, thus, advances the literature by connecting the state of hypertension care cascade with population level hypertension management outcome.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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Summary

What is known about topic

- Population coverage at different levels of hypertension care cascade is reported in various studies.
- Population coverage at cascade levels varies by sociodemographic characteristics.
- The status of coverage at certain cascade levels is indicative of the state of hypertension management in a country.

What this study adds

- This study evaluates how improvement in population coverage at certain cascade levels would impact population level hypertension management.
- This study quantifies the required level of coverages at cascade levels to attain a hypertension management outcome.
- To attain a desired level of uncontrolled hypertension prevalence, coverage improvement is required at multiple cascade levels.

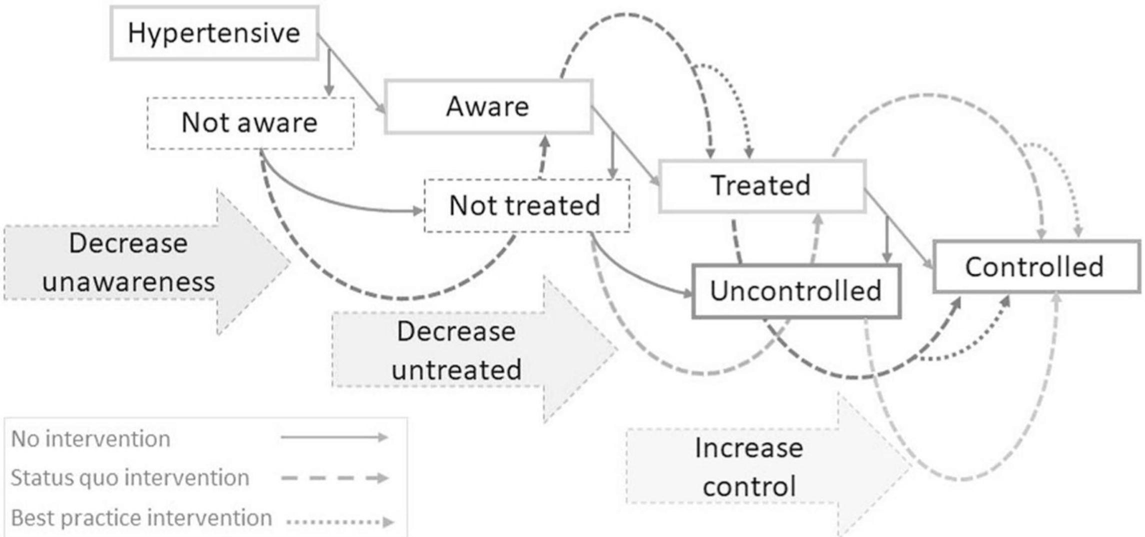

Fig. 1. Analytical framework of population coverage interventions in the hypertension control cascade.

Status quo intervention refers to keeping the status quo level of probabilities unchanged in subsequent cascade levels. Best practice intervention refers to setting probabilities as those of better performing health systems in the subsequent cascade levels.

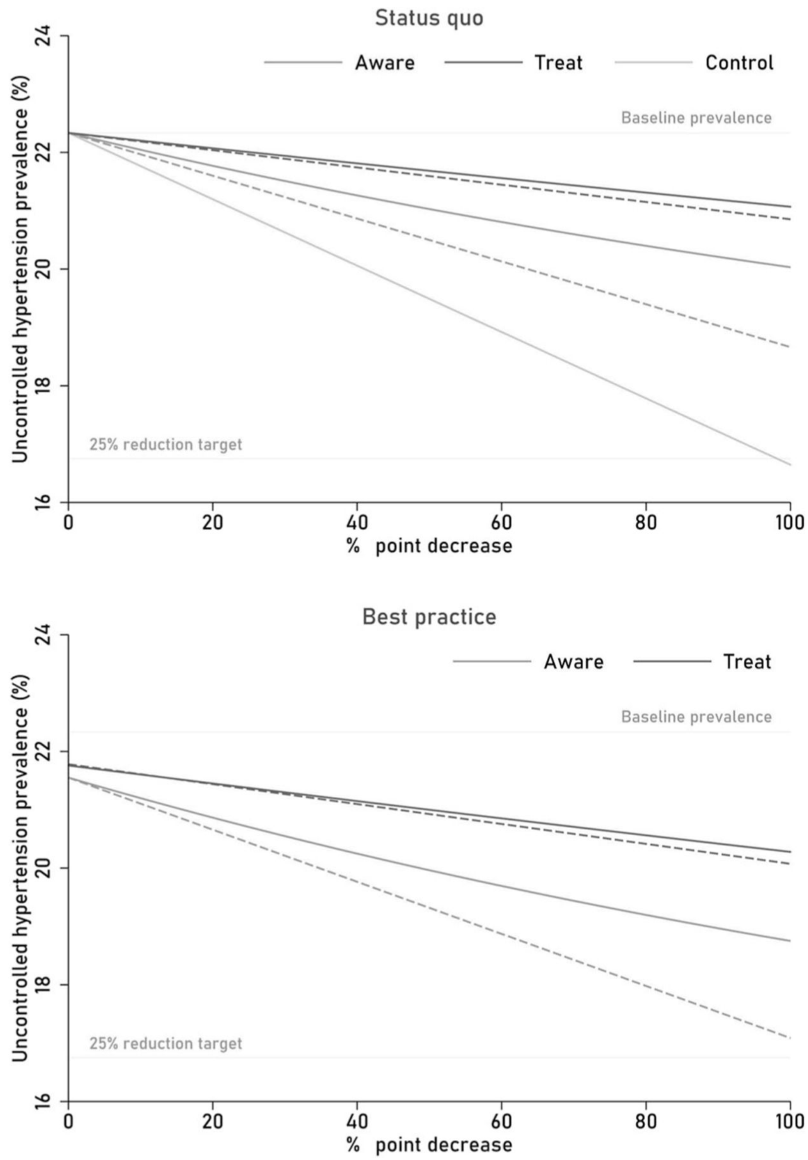

Fig. 2. Comparison of uncontrolled hypertension prevalence outcomes status-quo and best practice population coverage interventions at different cascade levels.

The dashed lines are showing estimates using zero elasticity, meaning treatment and control rate are constant for any additional aware and treated individuals. Status quo intervention refers to keep the status quo level of probabilities unchanged in subsequent cascade levels. Best practice intervention refers to setting probabilities as those of better performing health systems in the subsequent cascade levels. The baseline refers to 2018 Bangladesh National STEPS survey's estimate of hypertension prevalence (WHO, 2018).

Table 1.

Parameter values used in the estimation of hypertension prevalence outcomes for population coverage interventions.

Age groups	Probability of control among treated ($control_a$) Status quo	Best practice	Probability of treated among aware ($treatl_a$) Status quo	Best practice	Probability of aware among hypertensive ($aware_a$)	Hypertension Prevalence (htn_a)
15–24	68	78.38	67.77	71.48	30.33	9.22
25–39	36.23	41.76	62.37	65.79	41.93	22.16
40–54	38.75	44.66	70.8	74.67	56.5	38.89
55–69	35.99	41.48	81.09	85.54	60.3	47.25

Status quo intervention refers to keeping the status quo level of probabilities unchanged in subsequent cascade levels. Best practice intervention refers to setting probabilities as those of better performing health systems in the subsequent cascade levels. The prevalence and status quo rates were obtained from WHO, 2018. The best overall treatment rate of 73.4% and the best overall control rate of 45% (Geldsetzer et al. [8]) were spread across age groups based on the respective status quo rates ensuring that the mean was preserved.

Table 2.

Status quo intervention results by scenario and age groups using population coverage estimates from the 2018 Bangladesh National STEPS Survey.

		Uncontrolled hypertension prevalence (%)					
		Constant rates (Elasticity = 0)			**Variable rates (Elasticity ≠ 0)**		
Awareness							
Age groups	**Baseline**	**Scenario-1**	**Scenario-2**	**Scenario-3**	**Scenario-1**	**Scenario-2**	**Scenario-3**
15–24	7.93	6.45	5.71	5.27	6.99	6.68	6.54
25–39	20.06	18.6	17.88	17.44	19.04	18.64	18.43
40–54	32.87	30.54	29.38	28.69	31.13	30.37	29.94
55–69	38.93	36.19	34.83	34	36.86	35.93	35.41
Total	22.33	20.5	19.58	19.03	21.03	20.5	20.21
Relative reduction		8.20	12.32	14.78	5.82	8.20	9.49
Treatment							
Age Groups	Baseline	Scenario-1	Scenario-2	Scenario-3	Scenario-1	Scenario-2	Scenario-3
15–24	7.93	7.63	7.47	7.38	7.67	7.54	7.46
25–39	20.06	19.42	19.11	18.92	19.51	19.25	19.09
40–54	32.87	31.62	31	30.63	31.77	31.24	30.93
55–69	38.93	37.96	37.48	37.19	38.07	37.65	37.4
Total	22.33	21.59	21.22	21	21.68	21.37	21.19
Relative reduction		3.31	4.97	5.96	2.91	4.30	5.11
Control							
Age groups	Baseline	Scenario-1	Scenario-2	Scenario-3	Scenario-1	Scenario-2	Scenario-3
15–24	7.93	7.63	7.48	7.39	-	-	-
25–39	20.06	18.21	17.29	16.73	-	-	-
40–54	32.87	28.1	25.72	24.29	-	-	-
55–69	38.93	31.54	27.84	25.62	-	-	-
Total	22.33	19.49	18.07	17.21	-	-	-
Relative reduction		12.72	19.08	22.93			

Baseline refers to estimates from the 2018 National STEPS survey. Scenarios—1, 2, and 3 respectively refer to 50%, 75%, and 90% reduction in unaware, untreated, and uncontrolled for respective care cascade phases. Elasticity = 0 refers to constant treatment and control rate for any added aware and treated individuals.

Table 3.

Best practice intervention results by scenario and age groups using best practice population coverage estimates from literature.

		Uncontrolled hypertension prevalence (%)					
		Constant rates			**Variable rates**		
		Elasticity = 0)			**(Elasticity ≠ 0)**		
Awareness							
Age groups	**Baseline_{BP}**	**Scenario-1**	**Scenario-2**	**Scenario-3**	**Scenario-1**	**Scenario-2**	**Scenario-3**
15–24	7.66	5.86	4.96	4.42	6.51	6.13	5.96
25–39	19.61	17.84	16.95	16.42	18.37	17.88	17.62
40–54	31.57	28.74	27.33	26.49	29.46	28.53	28.01
55–69	37.14	33.81	32.15	31.15	34.62	33.5	32.86
Total	21.55	19.32	18.2	17.53	19.96	19.32	18.97
Relative reduction		10.35	15.55	18.65	7.38	10.35	11.97
Treatment							
Age groups	Baseline_{BP}	Scenario-1	Scenario-2	Scenario-3	Scenario-1	Scenario-2	Scenario-3
15–24	7.74	7.38	7.21	7.1	7.43	7.28	7.19
25–39	19.74	19.01	18.64	18.42	19.1	18.8	18.63
40–54	31.95	30.51	29.8	29.37	30.69	30.08	29.72
55–69	37.66	36.55	35.99	35.65	36.67	36.18	35.9
Total	21.78	20.93	20.5	20.24	21.03	20.67	20.46
Relative reduction		3.90	5.88	7.07	3.44	5.10	6.06

Scenarios—1, 2, and 3 respectively refer to 50%, 75%, and 90% reduction in unaware, untreated, and uncontrolled for respective care cascade phases. Baseline estimates incorporate best-practice aware and treatment rates showing how better treatment and control rates could decrease uncontrolled hypertension prevalence without any population coverage intervention. Elasticity = 0 refers to constant treatment and control rate for any added aware and treated individuals.