Modeling the Impact of Transcendental Meditation on Stroke Incidence and Mortality

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Objectives: Meditation has shown promise in clinical trials in reducing systolic blood pressure, one of the main risk factors for stroke. We aim to estimate the potential benefits of popularizing meditation on stroke incidence and mortality in the United States (U.S.). *Methods:* We developed a dynamic population-based microsimulation model to simulate the disease progression of each individual and compute disease burden. We calibrated the microsimulation model for stroke incidence and further validated it by comparing the stroke-related mortality for each age group generated by the model with that observed in the U.S. We used the population simulation model to estimate the effects of meditation intervention on the number of stroke cases and deaths over a course of 15 years. *Results:* Our results show that we could avert nearly 200,000 stroke cases and 50,000 stroke-related deaths over the course of 15 years. Our sensitivity analysis reveals that most of the benefits come from applying the intervention for individuals older than 60 years. In addition, meditation acceptance and adherence rate play a critical role in its effectiveness. *Conclusions:* The practice of meditation, if properly utilized along with the regular antihypertensive medication, could substantially alleviate the burden of stroke in the U.S. In order to design an effective meditation program, policymakers may prioritize funding to the programs that aim to encourage older individuals to practice meditation.

Key Words: Meditation—microsimulation—stroke incidence—stroke mortality—medication adherence

Cardiovascular diseases account for more than USD 500 billion in health care expenditures in 2010 alone.[1] Among these cardiovascular diseases, stroke is the fifth leading cause of death in the United States (U.S.),[2] costing the country USD 33.9 billion annually.[3] Around 800,000 people in the US have a stroke on average each year,[3] with an annual figure of about 130,000 stroke mortality cases—1 out of every 19 deaths.[4] The number of people living with stroke is projected to increase by 4 million by 2030,[5] posing a substantial burden for the aging society in the U.S. The World Health Organization estimated 6.7 million stroke deaths worldwide in 2012 and 33 million of stroke

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survivors (about half in high-income countries and half in low-/middle-income countries) who needed long-term follow-up and secondary preventive measures.[6]

Among major preventable causes of stroke, high blood pressure affects approximately 1 in 3 adults in the U.S. and thus hypertension control becomes one of the priorities in stroke prevention.[7] Pharmacological treatment of hypertension, however, faces the potential challenges from the risk of adverse effects[8] and difficulty in adherence,[9] hence the need to assess the long-term benefits of various lifestyle modification interventions as ambulatory alternatives to pharmacological and invasive therapies.

Among lifestyle modification interventions aimed at blood pressure control, meditation interventions including transcendental meditation[10,11] and breathing awareness meditation[12,13] have been shown to be effective in lowering both systolic blood pressure (SBP) and diastolic blood pressure among people with hypertension or prehypertension.[14] Transcendental meditation has also been shown as effective in reducing the "hard" outcome of mortality.[15] These meditation interventions share the common characteristics of using clearly defined specific techniques involving self-induced state or self-focus skill ("anchor").[16] Transcendental meditation has been shown to modulate the physiological response to stress via neurohumoral activation.[17] The neurobiological pathway between meditation intervention and blood pressure decrease might be that mediation influences one's physiological responses to affective processes including anxiety and perceived stress.[18,19] A recent scientific statement from the American Heart Association systematically reviewed the studies on potential benefits of meditation on cardiovascular risk and concluded that meditation may be used as an adjunct to guideline-based cardiovascular risk reduction, particularly considering the low risk of this lifestyle intervention.[20]

Meanwhile, a 2012 study of 29 integrative medicine centers and programs across the U.S. found that among all integrative medicine therapies, these mind-body approaches are the least reimbursed by insurers and most of such services were paid for by cash from the patients,[21] which signals a possible missed opportunity to lower the burden of illness from cardiovascular diseases. Thus, a model-based exploration about the long-term effectiveness of meditation interventions at the population level could help us better understand the potential benefits of increasing these interventions among people with elevated risk for cardiovascular diseases including stroke.

Simulation models provide a controlled and systematic approach to evaluate the potential impacts of interventions and health policy makers have used them extensively to estimate the cost and benefits of emerging and established interventions.[22] For example, the Prevention Impacts Simulation Model (PRISM) compares a variety of interventions in three domains of care, air pollution, and lifestyles for reducing cardiovascular risks in the U.S.[23] Sundberg, Bagust, and Terént[24] used Swedish data to develop and calibrate a model estimating the costs of stroke services, a model which operates by incrementing patients' experience of stroke events and their outcomes in annual steps. Various policy models have been built to evaluate the comparative efficacy of hypertension control measures, including the Coronary Heart Disease Policy Model that compared the long-term cost-effectiveness of antihypertensive medications[25] and the simulation of sodium reduction in the U.S. population.[26] In this study, we develop a dynamic population simulation model to quantify the prevention potential of meditation intervention on stroke trends in the U.S. Model parameters are drawn from documented evidence about transcendental meditation and health outcomes.[10] Our calibration of the simulation model is based upon data from the Centers for Disease Control and Prevention (CDC)'s online query system of "underlying causes of death."[27]

Methods

We create a simulation model to represent a population of individuals where the evolution of each individual is governed by a microsimulation model. We simulate the births and deaths for each individual to create a dynamic population that resembles the age and SBP structure of the U.S. population. In each calendar year, 1 of 3 major stochastic events occur in the model: (i) each simulated individual may die due to nonstroke-related causes, according to a probability, which is calculated for each age group; (ii) he/she may die due to stroke with a probability calculated based on an adapted Cox proportional hazards model comprising age, systolic blood pressure, and the calendar year; (iii) he/she may survive the year and then moves on to the next calendar year.

We start the simulation of the U.S. population in the census year of 1999 and calibrate the model by comparing the number of stroke-related deaths generated by the model with that observed in historical data from 1999 to 2013.[27] Then, we use the model to predict the impact of transcendental meditation intervention on stroke mortality in the U.S. population over a course of 15 years through 2028. We model the acceptance rate for meditation intervention among individuals as not everybody receiving a meditation intervention chooses to attend the teaching sessions and assume that these people do not benefit from meditation. Our model also simulates the adherence rate to the meditation intervention in each calendar year simulated, and we assume that the blood pressure goes back up to the no-intervention level once the individual chooses not to adhere to the practice in a given year. Next, we elaborate on microsimulation and population simulation model development.

Overview of Microsimulation Model

The population model is based on an individual-based microsimulation that replicates the probabilistic dynamics of stroke in an individual's life course. The model tracks the age and SBP of an individual on a yearly basis. While age increases by 1 for each calendar deterministically, SBP changes over time based on age groups, i.e., we update the SBP of an individual due to aging according to the patterns observed in the literature.[28] Aligned with literature, we discretize age into 6 age groups namely 25-45, 45-55, 55-65, 65-74, 75-85, and greater than 85 years, respectively for SBP updates.[27] The progression of each individual at a time period is based on the following 3 stochastic events.

First, an individual may die due to nonstroke-related causes. We estimate the probability of death in each age group from the life table, which provides a direct relation between age and probability of death.[29] Life expectancy is used to confirm that the model replicates the desired outcomes. Second, an individual may experience a stroke with a probability, which is calculated based on a validated Cox proportional hazards model.[30] However, since we use age, SBP, and calendar year as risk factors in calculating the probability of stroke, we adapt the equation and calibrate the model accordingly. That is, we condense other risk factors in the equation into a constant and estimate it via trial and error such that the number of stroke cases produced by the model matches with that observed from historical data in the U.S. In particular, we create the U.S. population in 1999, run the simulation model for a year, and compute the total number of stroke cases in each age group. We further validate the model by comparing the stroke mortality in each age group reported in historical data with that generated by the model. Third, if an individual experiences a stroke, he/she may die due to stroke according to a probability ("the case fatality") that depends on age group.[27]

In order to capture the real-life impact of meditation on individuals, we simulate 2 more characteristics for each individual: acceptance and adherence to meditation practice. We define acceptance rate as the probability that an individual ever attends a meditation program during the course of his/her life. Also, we define adherence as the probability that an individual, who has already attended a meditation program, complies with the intervention practice. In order to estimate the acceptance rate, we consider the work by[31] who studied mindfulness-based cognitive therapy (MBCT) to reduce rates of relapse of major depressive disorder. They used a 20% acceptability rate for MBCT among individuals with depressive disorder. Also, in order to estimate the adherence rate, we consider the results of 2 studies that reported the adherence of individuals to meditation programs. In particular, Raskin et al conducted a controlled study and compared muscle biofeedback, transcendental meditation, and relaxation therapy to evaluate their efficacy in the treatment of chronic anxiety, where 55% of participants completed the course of treatment.[32] In addition, Shannahoff-Khalsa et al studied the use of Kundalini yoga meditation for treatment of obsessive-compulsive disorder and observed that only 67% of participants completed the course of treatment.[33] Therefore, we assume that the acceptance rate of individuals follows a normal distribution with mean 0.20 and standard deviation 0.04, and adherence of individuals follows a normal distribution with mean 0.60 and standard deviation 0.04.[34] We truncate the normal distributions of these 2 rates at 0% and 100% and we assume that acceptance and adherence rates do not change over time. As meditation's impact on SBP is larger with older patients,[11] we assume that if an individual attends a meditation class and complies with its practice in a period, his/her SBP reduction will follow an age-dependent dosage. However, if an individual does not comply with the intervention practice in a period, his/her SBP returns to its no-meditation SBP trajectory.

Overview of Population Model

We extend the individual microsimulation model described above by running multiple, unique, and simultaneous copies of the model to represent a population of individuals and to simulate the effect of applying a variety of intervention scenarios. At each period, new individuals are added to the first age group of the population, i.e., the 25-44 age group. We set the birth rate to be 0.012, which is the rate observed in the U.S. over the past 2 decades.[35] At each time period, the microsimulation model simulates the probability of having a stroke event for each individual in the sample. The model is, therefore, able to produce the number of stroke new cases and deaths, as well as life expectancy. We use the population simulation model to estimate the number of stroke cases and deaths for a course of 15 years and investigate the impact of implementing a transcendental meditation intervention on stroke trends.

One risk factor in the Cox proportional hazards model, used to calculate the probability of stroke, is calendar year. In order to estimate the coefficient of this risk factor, we first create the U.S. population (older than 25) in 1999 according to the same age and SBP distribution observed in the data and then calibrate the annual numbers of stroke-related deaths from 1999 to 2013 to those annual figures observed from CDC "Underlying Causes of Deaths 1999-2013." The calibration procedure is similar to that in the microsimulation model. Table 1 describes the model variables and parameters.

Simulations

We create an initial population of individuals representing the U.S. population in 1999, since the calendar year of 1999 is the first year for which we have data for calibration. The age and SBP distributions mimic those of the U.S. reported in the literature.[24] We simulate the population until 2013 for calibration purposes described above. In the base case, we simulate the population until 2028, where we assume that meditation intervention is applied for individuals with a SBP of greater than 140 mmHg and age older

Table 1. *Model parameters and variables*

Parameter (P) /variable(V)	Description	Data source for calibration
Age (P)	Age of each individual at each time	Compressed mortality file 1999−2014[*]
Systolic blood pressure (P)	Systolic blood pressure of each individual at each time	National Health and Nutrition Examination Survey (NHANES)[†]
Baseline systolic Blood pressure (P)	Systolic blood pressure of an individual in an intervention-free setting	National Health and Nutrition Examination Survey (NHANES)[†]
Acceptance rate (V)	The probability that an individual ever accepts the intervention and attends mindfulness programs	We used estimates on the acceptability of mindfulness-based cognitive therapy among depressed patients[‡]
Adherence rate (V)	The probability that an individual adheres to the meditation after intervention	the adherence rate of individuals to documented mindfulness programs[§]
Acceptance (P)	Binary variable that determines if an individual accepts the intervention	Estimated from the inverse of cumulative density function of the unit uniform distribution and attendance rate
Adherence (P)	Binary variable about whether an individual adheres to intervention at each time	Estimated from the inverse of cumulative density function of unit uniform distribution and adherence rate
Stroke risk (P)	Calculates the stroke risk of each individual based on age, SBP, and adherence	Based on an adapted validated proportional Cox hazards model[‖]
Non-stroke mortality rate (V)	Calculates the nonstroke death rates according to the age of an individual	Based on mortality rates for each age group reported[*]
Stroke-related mortality rate (V)	Calculates the death rate of an individual who developed a stroke according to his/her age	Based on stroke mortality rates for each age group[*]
Birth rate (V)	The birth rate by which individuals are born to the US population each year	National Vital Statistics Reports[¶]

[*]Centers for Disease Control and Prevention (CDC), 2015. Compressed Mortality File 1999−2014. *CDC WONDER On-line Database*, compiled from Compressed Mortality File, 2015.

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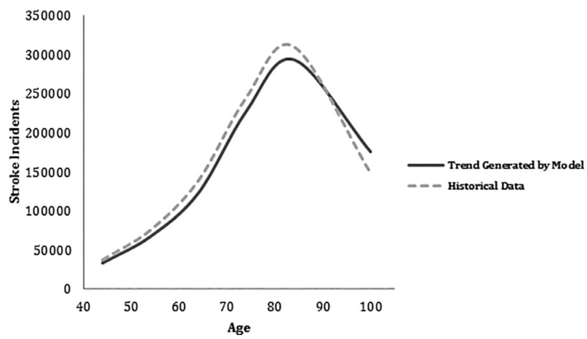

Figure 1. *Calibration of microsimulation model. Note: Figure 1 shows stroke incidence for each age group generated by the model as well as the historical data observed in the US in 1999.*

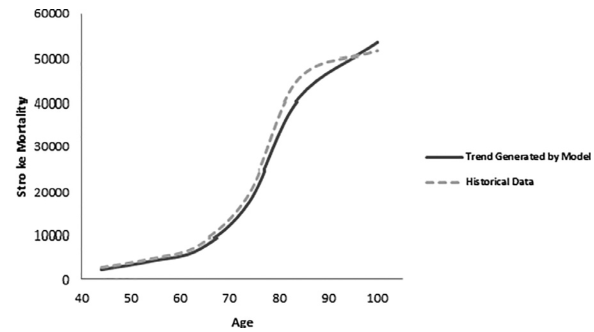

Figure 2. *Validation of microsimulation model. Note: Figure 2 shows the stroke-related mortality in each age group generated by the model as well as the historical data observed in the US in 1999.*

than 40 years, while the acceptance and adherence rate expected values are set to 20% and 60%, respectively. We conduct a variety of one-way and two-way sensitivity analyses to investigate the robustness of our results, as well as identify the key factors on outcomes by varying the model parameters. For example, we change the acceptance and adherence rate between [10%, 40%] and [30%, 90%], respectively. In order to find the age group, which could mainly benefit from the intervention, we apply it to individuals of 50 years or older and 60 years or older as well. A similar analysis is run for the SBP threshold for intervention, namely, 150 mmHg and 160 mmHg. Finally, we investigate a combination change in acceptance and adherence rate in a two-way sensitivity analysis to derive lower and upper bounds on such benefits.

Results

Figure 1 shows the result of the microsimulation model calibration where we compare stroke incidence generated by the model with the actual one observed in 1999. Figure 2 shows the results of the validation phase where we compare the stroke mortality generated by the model with that observed in each age group in 1999. Figure 3 shows the result of the population simulation model calibration where we compare the number of stroke-related deaths from 1999 to 2013 generated by the model with that observed in historical data. Note that since the model is stochastic, to provide stable estimates, we repeat each simulation 30 times and report the average and 95% confidence interval (CI) of results.[36] Note that the model properly identifies and mimics the trend of stroke mortality over time especially at the beginning and the end of the simulation horizon. However, there is a gap between the model and data in the middle, which might be due to time-specific secular shocks[37] (e.g., pharmacological breakthrough, policy changes, etc.) for mortality in the population that we did not model. We did not recalibrate the model to incorporate such secular shocks as the model does not consider them and recalibration may result in overfitting,[38] which may reduce the reliability of model prediction in the future.

In our base case analysis, where we assume that the meditation intervention is applied for individuals with a SBP of greater than 140 mmHg, age of 40 years or older, and the acceptance and adherence rate expected values are set to 20% and 60%, our results show that we could avert 206,150 (95% CI of [180,082-232,218]) stroke new cases and 50,096 (95% CI of [27,752-72,440]) stroke-related deaths over the course of 15 years (Fig 4). Panel (A) shows the prediction for the number of stroke new cases over a course of 15 years for 2 scenarios: (i) meditation intervention is not implemented, and (ii) meditation intervention is implemented at the acceptance rate of 20% and adherence rate of 60%. Similarly, Panel (B) shows the number of stroke-related deaths for the abovementioned scenarios. We also estimate the cost saving that could be achieved by considering the meditation intervention. The average cost of care for a patient up to 90 days after stroke is approximately $15,000.[39] Therefore, based on our assumption of the acceptance rate of 20% and adherence rate of 60%, a total monetary benefit of nearly three billion US dollars is achievable due to this intervention. In order to calculate the cost needed for implementing the intervention, we consider a price of USD 960[40] for each individual attended the program. In the base case, the intervention is applied to nearly 12.5 million individuals, which translates to approximately USD 12 billion cost of intervention. Under the base assumptions, the cost of intervention needs to be nearly USD 250 per person for the cost saved from averting stroke cases to fully cover the meditation intervention cost. Our sensitivity analyses results show that targeting hypertensive individuals older than 60 years could have more potential to be cost-saving, as the breakeven point is about USD 300 for this group. In our base case we consider a 90-day period cost of $15,000 after stroke incidence for cost benefit analysis. However, in a sensitivity analysis, we use an estimation of $27,000 as the estimated annual stroke-related direct medical costs.[41] In this case, the benefit under the same assumptions increases to USD 5.4 billion instead of USD 3 billion. Therefore, the cost of intervention could be 430 per person for the cost saved from averting stroke incidences to fully cover the intervention costs (Fig 5).

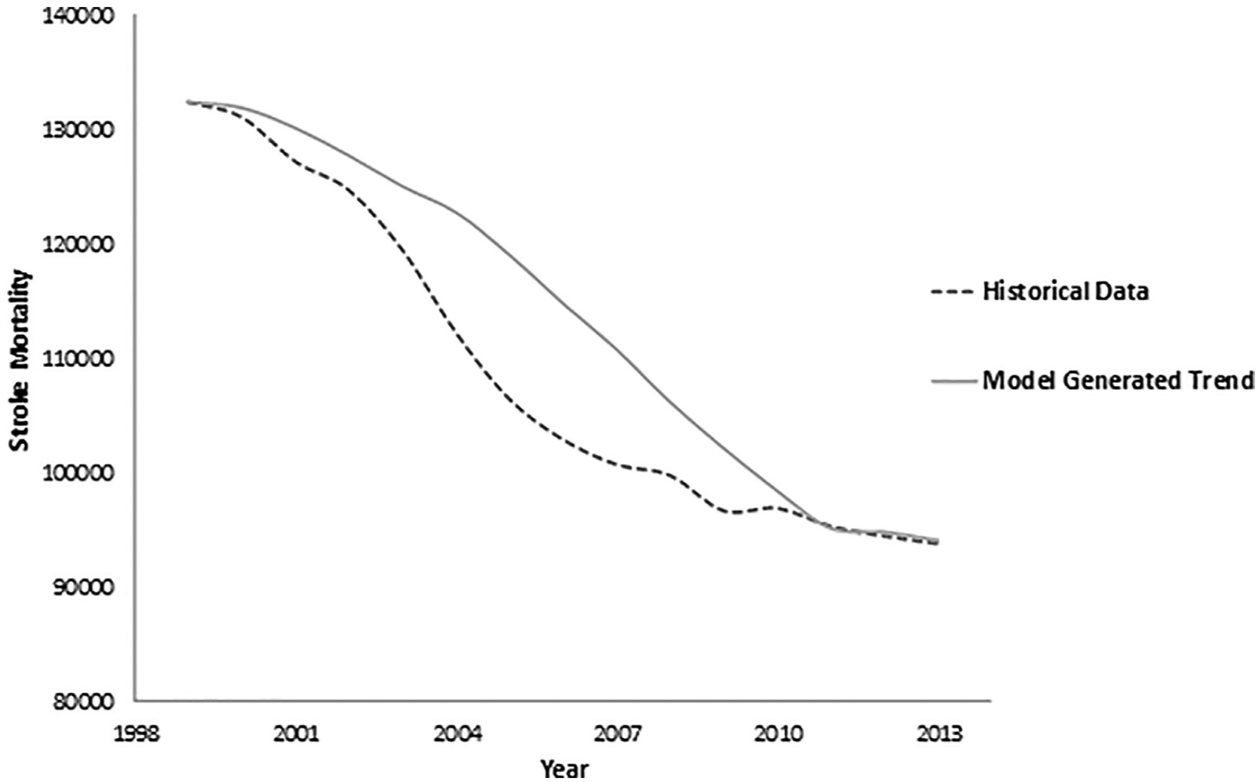

Figure 3. *Calibration of population model. Note: Figure 3 shows the number of stroke-related deaths generated by the model as well as the historical data observed in the US from 1999 to 2013.*

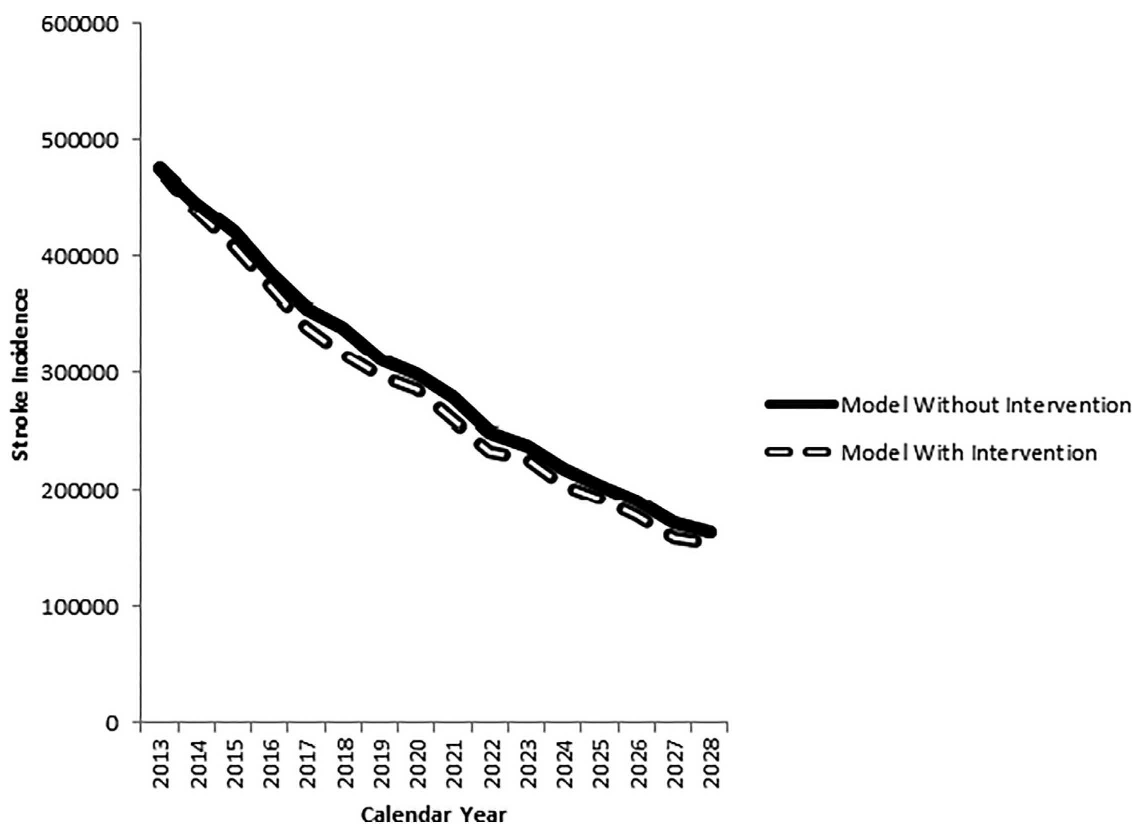

Figure 4. *Reduction in stroke incidence by applying the intervention. Note: Figure 4 depicts the results of applying the intervention on stroke incidence trend. In particular, the solid line shows the stroke incidence in an intervention-free setting and the dotted line shows that in a setting where the intervention is implemented. Results show we could avert 206,150 strokes (95% confidence interval [180,082; 232,218]).*

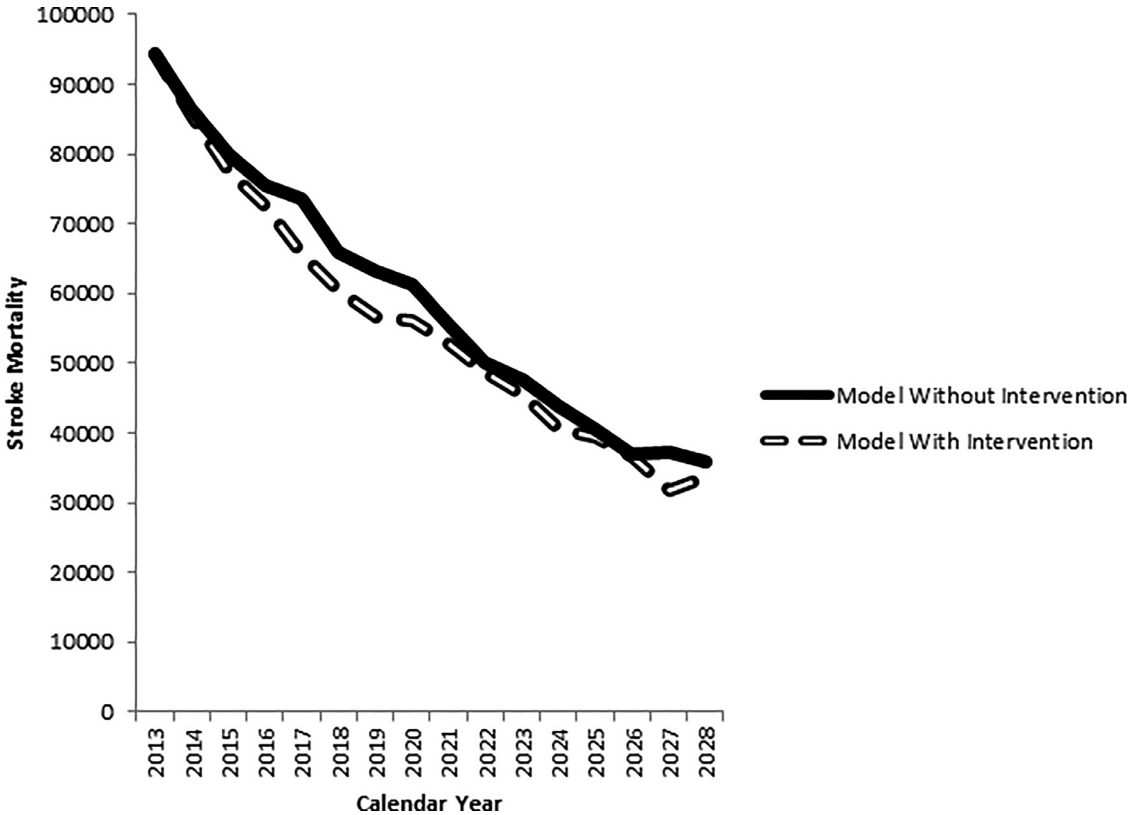

Figure 5. *Reduction in stroke mortality by applying the intervention. Note: Figure 5 compares the predicted number of stroke-related mortality produced by the model in 2 scenarios. The solid line shows the number of stroke-related deaths in an intervention-free setting and the dotted line shows that in a setting where the mindfulness meditation intervention is applied. The results are reported over a period from year 2013 to 2028. Results show that we could avert 50,096 (95% confidence interval [27,752; 72,440]) stroke-related deaths.*

As Table 2 shows, in the base case, we apply the intervention to individuals with a SBP of greater than 140 mmHg and age of greater than 40. In one sensitivity analysis, we considered 2 other thresholds for applying the intervention, namely, 150 mmHg and 160 mmHg. Our results show that by increasing the intervention initiation threshold to 150 mmHg, the number of stroke cases averted, and the number of stroke-related deaths averted, compared to the intervention-free setting, would reduce by 18.4% and 21.1%, respectively. Similarly, by increasing the intervention initiation threshold to 160 mmHg, the number of stroke cases averted, and the number of stroke-related deaths averted, compared to the intervention-free setting, would reduce by 74.5% and 69.2%, respectively.

In a sensitivity analysis, we apply the intervention to a variety of age groups. In particular, we assume that the intervention is applied to individuals older than 50 and 60 years old and our results show that the magnitude of change in the number of stroke cases and stroke-related deaths is less sensitive compared to other variables such as SBP threshold, acceptance rate, and adherence rate. This observation indicates that most of benefit comes from applying the intervention to hypertensive individuals older than 60 years. As Table 2 shows, both acceptance rate and adherence rate had a significant impact on results. When the acceptance rate drops to 10% (from base 20%), the benefits in terms of number of stroke cases averted almost halved and when the acceptance rate increases to 40%, the benefits in terms of number of stroke cases averted almost doubled. Also, if the average adherence rate drops to 30%, the number of stroke cases averted, and the number of stroke-related deaths averted, compared to the intervention-free setting, would decrease by 27.1% and 24.1%, respectively. Moreover, if the average adherence rate increases to 90%, the number of stroke cases averted, and the number of stroke-related deaths averted, compared to the intervention-free setting, would increase by 24.5% and 25.2%, respectively. Our two-way sensitivity analysis also confirms the significance of individuals' acceptance and adherence in the effectiveness of the intervention. This observation suggests that for designing an effective meditation program, policy makers may prioritize funding to the programs that aim to improve the compliance of individuals to meditation.

Discussion

Meditation is one of the emerging lifestyle techniques that address multiple risk factors of cardiovascular diseases, including stress, and elevated blood pressure. This

Table 2. *Sensitivity analysis for 15-year projected period*

Scenarios	Number of total strokes averted	Number of total deaths averted
Note: In the base case, all individuals in the model with a SBP of greater than 140 mmHg are considered for the intervention. All parameters are set to those reported in Table 1. The numbers in parenthesis indicate a 95% confidence interval.		
Base intervention	206150 ([180082,232218])	50096 ([27752, 72440])
One-way sensitivity analysis: In the following, for each row we keep all the parameters fixed to those reported in Table 1 and change the variable to the subscript. For example, SBP_{150} denotes the case where the intervention is applied to only those individuals whose SBP is more than or equal to 150 mmHg. Age_{50} denotes the case where the people only above 50 years of age are considered for the intervention. $Acceptance_{10\%}$ is used to specify that the average acceptance for intervention is set to 10% in the population and $Adherence_{30\%}$ shows that the average adherence rate to intervention is set to 30%.		
SBP_{150}	168150 ([142082,194218])	39520 ([17176,61864])
SBP_{160}	52566 ([26498,78634])	15390 ([-6954,37734])
Age_{50}	191420 ([165352,217488])	45473 ([23129,67817])
Age_{60}	162603 ([136535,188671])	42750 ([20406,65094])
$Acceptance_{10\%}$	112565 ([86497,138633])	26919 ([4575,49263])
$Acceptance_{40\%}$	395777 ([326697,464857])	98357 ([46964,140809])
$Adherence_{30\%}$	150085 ([144293,155878])	38014 ([32221,43806])
$Adherence_{90\%}$	256810 ([230742,282878])	62743 ([40399,85087])
Two-way sensitivity analysis: In the following, for each row we concurrently change 2 variables and other parameters are fixed to those reported in Table 1. For example, $Acceptance_{40\%}$ and $Adherence_{90\%}$ shows that for that setting the acceptance is set to 40% and adherence to 90% and other parameters are set to those reported in Table 1.		
$Acceptance_{40\%}$ and $adherence_{90\%}$	465753 ([439685,491821])	115646 ([93302,137990])
$Acceptance_{10\%}$ and $adherence_{30\%}$	78434 ([75538,81331])	19767 ([17284,22249])

Summary: This table reports the statistics related to stroke new cases and stroke-related deaths averted for a variety of scenarios for the entire 15-year projected period. Results show that with an increase in the SBP threshold above which we apply intervention, the number of stroke incidents averted and stroke-related deaths averted reduces. However, changing the age threshold above which we apply the intervention did not significantly change the simulation outcomes. As we decrease the adherence rate or attendance rate the stroke mortality increases. The effect of acceptance is larger than adherence according to the results. The key factors are the acceptance and SBP threshold because they show a much larger impact on the model outputs in terms of stroke mortality and incidence.

paper uses a simulation model to explore the potential impact of meditation on stroke incidence and mortality among the US population above 25 years of age. A hypothetical transcendental meditation intervention with an acceptance rate of 20% and adherence rate of 60% among people with systolic blood pressure greater than 140 mmHg and 40 years or older averts approximately 200,000 strokes and 50,000 stroke-related deaths over a course of 15 years. This outcome is very sensitive to the acceptance and adherence rates we assume: benefits are almost proportional to the acceptance rate; at an adherence rate of 30% the number of stroke deaths averted drops to nearly 38,000-over a course of 15 years and if we assume the adherence rate is 90% the number of stroke deaths averted increases to around 63,000. We settle to undertake the first model-based projection study of a hypothetical diffusion of meditation practice among people at elevated risk for cardiovascular diseases. The microsimulation nature of our model makes it easy to estimate what the total benefits of meditation diffusion will look like for a defined subset of the US population. For example, a state government agency or an insurance company, interested in curbing stroke-related costs and productivity losses, can easily take a subset of our simulated US population and explore the extent to which a meditation promotion program could help with their goals. As the mortality benefits of meditation as simulated in our model is mediated through a decrease of systolic blood pressure, this model can also be adapted to simulate the mortality benefit of any intervention proven to lower systolic blood pressure (e.g., physical activity, fasting, pharmacological intervention, surgical intervention, etc.).

Compared to other prevention modalities for hypertension management such as physical exercise[42] and healthy eating,[43] meditation practice has its advantage in that it could be less dependent on external conditions such as safe neighborhood,[44] easy access to fresh vegetable,[45] good weather,[46] or indoor exercise equipment, which may not be available for many hypertensive people. Nor does meditation practice require the patient to be free from disabilities to benefit from the modality as in the case of physical activity intervention, as many stroke survivors might be not fit enough to meet recommended physical activity level[47] but could be fit enough to sit through a meditation session.[48] In addition, a recent meta-analysis shows the impact on SBP from nontranscendental meditation is −3.77 mmHg (95% CI: −5.33,

−2.21) measured with 24-hour ambulatory blood pressure measurement,[49] not notably different from the effect of transcendental meditation on SBP (−4.26 mmHg, 95% CI = −6.06, −2.23). Thus, though the intervention effect estimates on blood pressure are drawn from a meta-analysis of transcendental meditation trials,[10] the implication of our simulation could be applicable to other meditation as well.

This study has several limitations. First, the duration of meditation could affect the clinical outcome of meditation,[50] yet due to lack of documented parameter estimates of the dose-response effect of meditation duration on blood pressure we are unable to incorporate the variable of meditation duration in our model. Second, our model only simulates 1 aspect of hypertension: systolic hypertension. A more comprehensive model of stroke mortality needs to include the diastolic blood pressure and its response to health interventions as well. Third, the projected health benefits based upon our model results are likely to be an underestimation of the total health improvement attainable through an increase in the uptake of meditation practice, since it improves medication adherence, other lifestyles and overall health related quality of life[48] in addition to its mortality benefits, and the benefits of transcendental meditation on mortality reduction is not limited to stroke mortality.[51]

Fourth, we are also aware that we might need to update the model assumption about the model's applicability to MBSR, since by 2014 a review of evidence still shows that mindfulness interventions' impact on physical parameters of vascular disease was "not yet established."[52] Our results are based on several assumptions on model inputs such as acceptance and adherence rate to meditation programs and practice. Estimating these parameters is challenging and needs several studies focusing on these important factors of meditation interventions. Acceptance rates in this study are based on the acceptability of mindfulness-based cognitive therapy designed to reduce rates of relapse of major depressive disorders. Therefore, the underlying assumption is that an average hypertensive individual's acceptance towards meditation is similar to that among patients who had depressive disorders before, whereas in reality people with a history of depressive disorder might find meditation more acceptable than people with systolic hypertension. Similarly, we extract the adherence rate to meditation practice in some programs in the literature and set our estimation for the adherence rate based on the ranges reported in the literature, whereas the study populations in those documented programs could be significantly different from the systolic hypertension patients we are trying to simulate.

Finally, we consider age and SBP to represent each individual in the population and do not model other characteristics such as gender and race, which might have impact on results, and meditation's impact on blood pressure might vary between these groups. To have a more comprehensive quantification of what meditation can do to improve population health, future models need to add in other types of evidence-based mortality benefits from meditation, as well as adding in the components of health-related quality of life.

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