Cost-Effectiveness Analysis of Annual Screening and Intensive Treatment for Hypertension and Diabetes Mellitus Among Prisoners in the United States

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Hypertension and diabetes mellitus are the most common chronic illnesses among adults. They occur in the prison population and are responsible for substantial morbidity, particularly after release. The prison setting offers an opportunity to initiate screening for and treatment of these conditions in an environment that is conducive to high levels of patient compliance. At present, in most correctional facilities, these diseases are diagnosed opportunistically and may not receive state-of-the-art treatment.

In this paper, a Monte Carlo simulation is constructed that projects the economic and health consequences over 20 years of initiating annual screening and intensive treatment for these illnesses. The model derives its underlying demographics from information supplied by the National Commission on Correctional Health Care. The prevalence of hypertension and diabetes are modeled by applying to this population the age-, sex-, and race-specific rates observed in the National Health and Nutrition Examination Survey III.[1] The occurrence of complications is then predicted using results of the Diabetes Control and Complications Trial, the Wisconsin Epidemiologic Study of Diabetic Retinopathy, and the Framingham Heart study.

Implementing the proposed program would, over the next 20 years, result in a gain of 386,108 life-years in the cohort of approximately 1.6 million persons currently incarcerated. The immediate and subsequent costs for screening and treating this population are $4,214,720,066, or $131.71 per prisoner per year. These costs are partially offset by concurrent reductions in expenditures for treating the complications of these diseases. When the conventional discount rate of 3 percent per annum is applied, the cost-effectiveness ratio for implementation is between $11,300 and $27,100 depending upon what levels of compliance and immediate costs of screening are assumed. Even under the worst-case scenario, this program is a more economical allocation of health care resources than many widely accepted preventive health practices.

The authors recommend that prison systems adopt annual screening for hypertension and diabetes and intensive treatment of both diseases to obtain tight control of both.

Introduction

Hypertension and diabetes mellitus are the two most common chronic illnesses among adults. Both are major risk factors for developing coronary heart disease and renal failure.

Hypertension is also the major risk factor for stroke, and one of the leading causes of peripheral vascular disease. Diabetes is the most common cause of blindness in adults and leads to painful neuropathy and amputation of limbs. It has been known for many years that treatment of hypertension reduces the incidence of complications. More recently, it has been demonstrated that tight

control of glucose in both Type I[2] and Type II[3] diabetes can also reduce the incidence of complications.

Prisoners are younger than the U.S. population as a whole and correspondingly have a lower prevalence of hypertension and diabetes. Screening for these diseases, even in this relatively low-prevalence population, might nevertheless be productive for several reasons:

- The prison population already has health care facilities and physicians at its disposal and makes frequent use of them; therefore, no costs to create capacity would be incurred.
- Prisoners do not lose income or free leisure activity while using the health care system; therefore, the usual indirect costs that encumber screening programs do not exist.
- Followup and adherence to dietary and medical regimens can be enforced in the prison environment to a greater extent than outside. (It might even be hoped that establishing a behavioral pattern of compliance with treatment in prison might lead to continued good compliance following release as well.)
- The direct screening costs for both diseases are modest, and the confirmatory evaluation of abnormal results is both inexpensive and safe.

The following analysis of the costs, consequences, and cost-effectiveness of screening and aggressive treatment for hypertension and diabetes mellitus in the imprisoned population of the United States has been carried out at the request of the National Commission on Correctional Health Care (NCCHC).

Methods

The major complications that are predicted to occur as a result of hypertension and diabetes mellitus among the current incarcerated population in the United States were identified through a Monte Carlo simulation model programmed using @Risk.[4] The costs and consequences of identifying and treating hypertension and diabetes among these prisoners were predicted and the cost-effectiveness ratio calculated. The cost-effectiveness ratio was defined as the increase in costs resulting from instituting screening and treatment divided by the increase in quality-adjusted life-years associated with that.

The simulation model projected the occurrence of the following outcomes:

- Coronary heart disease (CHD) including angina pectoris myocardial infarction.
- Congestive heart failure.
- Stroke.
- Hypertensive renal failure.
- Diabetic nephropathy progressing to renal failure.
- Diabetic neuropathy progressing to lower extremity amputation.
- Diabetic retinopathy progressing to blindness.
- Death.

The overall logic of the simulation was as follows:

- Assign sex, race, and initial age of the simulated subject according to the distributions known for the imprisoned population.
- Using age-, sex,- and race-specific distributions derived from the NHANES–III data, assign the simulated patient a smoking status, diabetic status, systolic blood pressure (SBP), total cholesterol, and high-density lipoprotein (HDL) cholesterol level. If the simulated subject is a diabetic, also assign a duration of diabetes and initial stage for diabetic retinopathy, neuropathy, and nephropathy.

Simulated followup begins at current age and continues for 20 years (or until the simulated patient "dies," whichever comes first). Each patient's current vital status; incarceration status; current SBP and lipid levels; and, if diabetic, current stage of diabetic retinopathy, neuropathy, and nephropathy are randomly determined on an annual basis. The probability of developing each of the study endpoints in this year is calculated, and then it is randomly determined which, if any, of such events occur.

Because CHD incidence rates are gender dependent and incidence rates of complications of diabetes differ by race, separate simulations were run for each combination of three racial or ethnic groups (white, Hispanic, and black) and both sexes. Twenty thousand subjects were simulated for each of these race-sex strata. The strata were then combined and the results adjusted to the racial/ethnic and sex distribution of the imprisoned population.

Population costs were calculated by applying average estimated unit costs to tallies of outcome events and person-years of morbid states and by assessing appropriate costs of screening, diagnostic followup, and treatment in the screen-and-treat strategy.

The Population

Demographics of the incarcerated population

Table 1 shows the numbers of prisoners of various ages, sexes, and races.[5]

Age-, sex-, and race-specific distributions of chronic disease

Appropriate sample weights were applied to the NHANES–III data (National Center for Health Statistics, 1997) to estimate smoking prevalence, SBP, total cholesterol, HDL, and prevalent cases of diabetes mellitus; analyses were carried out using Stata version 6.0.[6]

Smoking status. The case definition of smoking was defined as an affirmative response to the NHANES–III question about smoking within the past year because the risks of coronary heart disease associated with smoking are known to decline to near baseline rates after 1 year of abstinence. It was assumed that smoking status would not change over time. Table 2 shows the probabilities of being a smoker for a given age, sex, and race combination. These probabilities were used to predict smoking prevalence for each simulated individual.

Table 1. Demographics of the Incarcerated Population

Age	Black Male	Black Female	White Male	White Female	Hispanic Male	Hispanic Female
≤19	46,489	1,392	24,146	1,366	16,824	636
20–24	124,795	8,143	90,807	6,817	57,170	3,768
25–29	150,220	13,989	107,131	10,049	66,205	4,448
30–34	136,607	14,841	111,898	10,360	52,009	4,381
35–39	95,126	10,249	81,380	7,466	36,447	2,840
40–44	55,613	4,517	57,290	4,582	21,629	1,881
45–49	23,349	1,811	32,944	1,863	12,569	1,059
50–54	9,166	667	20,348	1,330	5,615	372
55–59	5,297	339	12,428	487	3,602	179
60–64	3,480	96	7,498	288	1,743	63
65+	3,564	155	5,297	235	548	10
Total	**653,706**	**56,199**	**550,167**	**44,843**	**274,361**	**19,637**

Table 2. Probability of Being a Smoker						
	Male			Female		
Age Group	White	Black	Other	White	Black	Other
≤19	0.230	0.154	0.103	0.270	0.043	0.006
20–24	0.410	0.268	0.306	0.333	0.212	0.095
25–29	0.378	0.324	0.288	0.390	0.298	0.004
30–34	0.363	0.403	0.431	0.334	0.370	0.005
35–39	0.369	0.517	0.374	0.274	0.313	0.258
40–44	0.319	0.487	0.395	0.236	0.318	0.116
45–49	0.354	0.525	0.386	0.280	0.352	0.088
50–54	0.325	0.444	0.191	0.222	0.266	0.050
55–59	0.273	0.464	0.548	0.237	0.356	0.193
60–64	0.207	0.375	0.090	0.246	0.235	0.351
≥65	0.147	0.247	0.359	0.112	0.112	0.118

Distribution of systolic blood pressure, initially and over time. Systolic blood pressure in homogeneous population groups follows an approximately log-normal distribution. SBP is known to be higher in African-Americans and in diabetics. The NHANES–III data were used to estimate the mean and standard deviation of the natural logarithm of SBP in each stratum of individuals defined by age group, sex, racial or ethnic group, and diabetes status. Each subject was assigned an initial SBP by sampling from a log-normal distribution with the corresponding parameters. The tails of the log-normal distribution are heavier than those of actual SBP distributions, so the corresponding values were truncated to limit the simulated SBPs to realistic values.

Blood pressure rises with age. This was modeled by adding an annual increment to the simulated blood pressure which equals the coefficient of age in the race-, sex-, and diabetes-specific regression of SBP with age in the NHANES–III data. Large random fluctuation caused by various factors occurs over time as well. The test-retest correlation of diastolic blood pressure measurements has been estimated to be 0.43[7] and that for systolic blood pressure is even lower.[8] More consistent blood pressure measurements require measurement procedures that have not been adopted in general clinical practice and are unlikely to be used in the correctional health care context. In each year of the simulation, a normally distributed, mean-zero, random increment to blood pressure was added to the previous year's blood pressure. The variance of the distribution was chosen to create a 1-year intercorrelation of 0.50 among SBP measurements. The principal reason for simulating SBP measurements (rather than hypertension) is to apply the American Heart Association (AHA) prediction formula[9] for CHD. Because the measurement procedures used in the Framingham study (from which the AHA formula is derived) are somewhat more rigorous than standard clinical practice, this enhanced intercorrelation seems reasonable.

To illustrate, for white males, the logarithm of initial SBP was sampled from a normal distribution with mean 0.00327 × age + 4.673 (+0.0268 if diabetic) and standard deviation 0.113. The resulting log SBP was trimmed to a minimum of 4.23 and a maximum of 5.5 (restricting SBP to the range 70–245). The exponential of this value was used as the initial SBP. For subsequent years, the logarithm of SBP was taken to be the previous year's log SBP + 0.00327 (to reflect aging) + a mean-zero normally distributed random fluctuation with standard deviation 0.08. The same trimming limits were applied and the result exponentiated to determine the next year's SBP. Similar procedures with

race- and sex-specific coefficients were used for women and blacks. SBPs for Hispanics were simulated using the equations for whites because analysis of the NHANES–III data found no substantial differences between these groups. Table 3 shows the regression equations used to predict the log of SBP for various racial and ethnic groups and both sexes.

Distribution of total cholesterol and HDL cholesterol, initially and over time. Total cholesterol and HDL also follow approximately log-normal distributions in homogeneous population groups. It is known that total cholesterol tends to be elevated and HDL cholesterol depressed among persons with high blood pressure compared with those with normal blood pressure, and among diabetics compared with nondiabetics. In addition, HDL cholesterol tends to be lower among those with higher total cholesterol. These intercorrelations could be captured by estimating the mean logarithm of total cholesterol from a race- and sex-specific regression equation involving age and systolic blood pressure and then estimating the mean logarithm of HDL cholesterol from age and total cholesterol. The process was similar to that outlined for SBP.

For white males, the logarithm of initial total cholesterol was sampled from a normal distribution with mean 4.03 + 0.2264 × SBP + 0.0038 × age, with standard deviation 0.1944, trimmed to limits of 4.3 and 6.55. For subsequent years, the logarithm of total cholesterol was incremented by 0.0038 + a zero-mean normally distributed error term with a standard deviation of 0.137, again trimmed to the same limits. The equations for females and nonwhites had different constant terms, but were otherwise the same. The same standard deviation was used for both sexes and racial groups. Table 4 shows the regression equations used to predict the logarithm of total cholesterol in race- and sex-specific groups.

For HDL cholesterol, the logarithm was sampled from a normal distribution with mean 3.769 −0.00064 × age + 0.00012 × total cholesterol and a standard deviation of 0.297 for white males. The trimming limits were 2.08 and 5.28. For females and nonwhites, separate equations and standard deviations were estimated, as shown in table 5.

Table 3. NHANES–III Regression Equations Used to Predict the Log of Systolic Blood Pressure

LogSBP Black Female = age × 0.0055882 + dm × 0.040263 + 4.557157	SD = 0.113
LogSBP Black Male = age × 0.0037727 + dm × 0.0289417 + 4.667224	SD = 0.112
LogSBP White Female = age × 0.0054558 + dm × 0.0552535 + 4.524341	SD = 0.113
LogSBP White Male = age × 0.0032679 + dm × 0.0267574 + 4.672714	SD = 0.113

Table 4. NHANES–III Regression Equations Used to Predict the Log of Total Cholesterol

Black Female = 0.2263468 × LogSBP + 0.0037968 × age + 4.0330064
Black Male = 0.2263468 × LogSBP + 0.0037968 × age + 4.0077188
White Female = 0.2263468 × LogSBP + 0.0037968 × age + 4.0524686
White Male = 0.2263468 × LogSBP + 0.0037968 × age + 4.027181

Table 5. NHANES–III Regression Equations Used to Predict the Log of HDL Cholesterol

Black Female = −0.0011172 × age + 0.0013044 × cholesterol + 3.790949	SD=0.2984
Black Male = −0.0003883 × age + 0.0004286 × cholesterol + 3.836287	SD=0.2963
White Female = −0.0000327 × age + 0.0003573 × cholesterol + 3.896419	SD=0.2963
White Male = −0.0005691 × age + 0.0001175 × cholesterol + 3.768782	SD=0.2967

As with SBP, for both total and HDL cholesterol values, Hispanics were treated as whites based on lack of significant differences. Separate parameter estimates for females and for blacks were used.

Diabetes: Prevalence, Duration, and Incidence

The case definition of diabetes mellitus used was: a history of using oral hypoglycemic agents or insulin preparations or a fasting blood glucose exceeding 125 mg/dL followed by a 2-hour specimen exceeding 140 mg/dL.

Diabetes prevalence

Table 6 shows the assumed prevalence of diabetes by age group, sex, and race. With the criterion for diabetes used, the number of cases of diabetes among Hispanics in the NHANES–III data was too small to provide stable estimates of prevalence in several age-sex subgroups. For this reason, in the model, the same prevalence rates were used for whites and Hispanics.

Diabetes duration

The rates of progression of complications of diabetes depend upon the duration of the disease. Time since diagnosis of diabetes was estimated using a model that was fitted to data from the NHANES–III survey. Within the NHANES–III survey, diabetes duration was defined as the difference between the date of examination and the date when the subject was first told of a diagnosis of diabetes. Graphical and descriptive exploratory analysis of this variable suggested that within narrow age groups, the distribution of duration followed an exponential distribution. The rate parameter for the distribution appeared to increase linearly with age. The duration of diabetes was treated as a survival time variable and fit an exponential regression model with age as a continuous predictor variable. Each simulated diabetic subject was assigned an initial duration of diabetes by sampling from an exponential distribution (truncated at current age) with the parameter calculated from the regression model.

$$Duration \sim Exponential\ (\alpha + \beta \times age)$$

Maximum likelihood estimates of $\alpha = 1.1$ and $\beta = 0.2$ were used. For each prevalent diabetic prisoner, a duration of diabetes was assigned by sampling from an exponential distribution with mean = $1.1 + 0.2 \times$ age.

Diabetes incidence

Age-, sex-, and race-specific incidence rates for diabetes mellitus are difficult to find. Because diabetes is not screened for routinely, is not reportable, and is initially asymptomatic, most

Table 6. Prevalence of Diabetes Mellitus

Age Group	Male White	Male Nonwhite	Female White	Female Nonwhite
≤19	0.001	0.009	0.011	0.009
20–24	0.004	0.006	0.004	0.006
25–29	0.004	0.008	0.001	0.017
30–34	0.003	0.012	0.009	0.017
35–39	0.027	0.014	0.018	0.017
40–44	0.038	0.036	0.047	0.062
45–49	0.051	0.107	0.032	0.084
50–54	0.086	0.120	0.062	0.116
55–59	0.118	0.244	0.081	0.157
60–64	0.136	0.226	0.128	0.133
≥65	0.127	0.195	0.103	0.164

newly diagnosed cases are not truly incident. The age-specific estimates of incidence shown in table 7 were derived from surveillance reports gathered by the Centers for Disease Control and Prevention (CDC).[10]

Diabetes: Prevalence, Incidence, and Progression of Complications

Stages of diabetic nephropathy—initial prevalence and progression

Following Eastman et al., an initial 10.5 percent prevalence of microalbuminuria among prevalent diabetics was assumed. Progression through frank proteinuria to end-stage renal disease was then simulated using duration-, sex-, and race-specific annual rates,[11] as shown in table 8.

Remarks about hypertension and renal disease

In addition to diabetic nephropathy, hypertensives are at risk of developing end-stage renal disease. Suitable data could not be identified on the incidence of renal failure by blood pressure, age, and race. Instead, total numbers of hypertensives that are being treated for end-stage renal disease under Medicare, broken down by age group, were obtained from the U.S. Renal Data System.[12] These numbers were divided by estimates from

Table 7. Incidence of Diabetes Mellitus

Age Group	Cases per 1,000 per Year
0–44	1.56
45–64	6.45
65+	4.18

Table 8. Rates of Progression of Complications of Diabetes

Race	Duration of Diabetes	From Normal to Microalbuminuria	Microalbuminuria Frank Proteinuria	Frank Proteinuria ESRD
White	0–4	0.0267	0.1572	0.0042
	5–9	0.0267	0.1572	0.0042
	9–11	0.0267	0.1572	0.0042
	12–13	0.0267	0.1572	0.0385
	14–20	0.0267	0.1572	0.0385
	21+	0.0267	0.1572	0.0740
Black	0–4	0.1215	0.1572	0.0042
	5–9	0.1215	0.1572	0.0042
	9–11	0.1215	0.1572	0.0042
	12–13	0.1215	0.1572	0.0385
	14–20	0.1215	0.1572	0.0385
	21+	0.1215	0.1572	0.0740
Hispanic	0–4	0.1719	0.1572	0.0042
	5–9	0.1719	0.1572	0.0042
	9–11	0.1719	0.1572	0.0042
	12–13	0.1719	0.1572	0.0385
	14–20	0.1719	0.1572	0.0385
	21+	0.1719	0.1572	0.0740

NHANES–III of the total numbers of hypertensives (defined as systolic blood pressure ≥140 mmHg) in these age groups. The resulting prevalence rates were taken to represent lifetime incidence. Annual incidence rates for hypertensives were then estimated by attributing the risk over the life expectancy of people in each age group. Although this method of estimating incidence is far from ideal, given the relatively small number of hypertensives and the low incidence of end-stage renal disease among them in the target population, even major errors in these estimates will exert little influence on the overall results of the analysis.

Stages of diabetic neuropathy—initial prevalence and progression

It was assumed that 3.5 percent of prevalent diabetics have symptomatic neuropathy. Incidence of symptomatic neuropathy and progression to amputation were simulated using duration-, sex-, and race-specific rates from Eastman et al.,[13] as shown in table 9.

Stages of diabetic retinopathy—initial prevalence and progression

The model of diabetic retinopathy was taken from the Wisconsin Epidemiologic Study of Diabetic Retinopathy.[14] For instance, it was assumed that 20 percent of prevalent diabetics already have nonproliferative diabetic retinopathy.

Diabetic retinopathy was modeled as having five stages: normal (R1), nonproliferative (R2), proliferative (R3), macular edema (R4), and visual acuity < 20/100 in better eye (R5). Progression through these stages can be direct, or stages R3 or R4 can be skipped with direct advancement from R2 to R4 or from R3 to R5. Table 10 summarizes the annual transition probabilities among these stages taken from Javitt et al.[15]

American Heart Association Model of CHD Risk

The Framingham study is the best known and longest running cohort study of the epidemiology of cardiovascular disease. Over the years, numerous formulas for predicting risk of coronary heart disease (or specific manifestations thereof) from the standard risk factors have been derived from the Framingham findings. To estimate the risk of CHD in the study model, a model developed by the American Heart Association that relies on age, gender, diabetes, smoking, systolic blood pressure, and total cholesterol/HDL cholesterol ratio as predictors was used.[16] That

Table 9. Simulation of Symptomatic Neuropathy and Progression to Amputation

Race	Duration of Diabetes (yrs.)	From Normal to Symptomatic	Symptomatic 1st Amputation	1st Amputation 2nd Amputation
White	0–8	0.0144	0.0280	0.1386
	9–13	0.0144	0.0350	0.1386
	14–19	0.0144	0.0467	0.1386
	20+	0.0144	0.1400	0.1386
Nonwhite	0–8	0.0432	0.0840	0.4158
	9–13	0.0432	0.1050	0.4158
	14–19	0.0432	0.1401	0.4158
	20+	0.0432	0.4200	0.4158

Table 10. Probabilities of Progression of Diabetic Retinpathy						
Race	Diabetes Duration	From R1 to R2	From R2 to R3	From R2 to R4	From R3 to R5	From R4 to R5
White	0–4	0.073	0.0025	0.047	0.088	0.05
	5–9	0.129	0.0090	0.095	0.088	0.05
	10–14	0.116	0.0095	0.092	0.088	0.05
	15+	0.113	0.0260	0.080	0.088	0.05
Black	0–4	0.154	0.0050	0.099	0.088	0.05
	5–9	0.272	0.0190	0.200	0.088	0.05
	10–14	0.245	0.0200	0.194	0.088	0.05
	15+	0.238	0.055	0.169	0.088	0.05
Hispanic	0–4	0.196	0.007	0.126	0.088	0.05
	5–9	0.346	0.024	0.255	0.088	0.05
	10–14	0.311	0.025	0.247	0.088	0.05
	15+	0.303	0.070	0.214	0.088	0.05

formula predicts the 4-year risk of incident CHD (defined as myocardial infarction, sudden death, and stable or unstable angina). A 1-year risk of incident CHD was calculated by assuming that the hazard is constant over the 4-year interval and applying the standard conversion formula.

Framingham-derived proportionate morbidity ratios

The American Heart Association formula predicts risk of CHD as a whole but does not distinguish among its various manifestations. Because different costs were to be assigned to different manifestations of CHD, the incidence of myocardial infarction and angina (both stable and unstable) were estimated as follows: Counts of incident cases of CHD, myocardial infarction, and angina were taken from the reports of the Framingham study.[17] Age-group- and sex-specific proportionate morbidity ratios were then calculated and applied. For example, among 55- to 64-year-old males in the Framingham study, 182 myocardial infarctions were observed among 305 incident cases of coronary heart disease. The ratio 0.597 was therefore used as the probability that a simulated subject with predicted incident CHD in a given year would have a myocardial infarction.

Other complications of hypertension

In addition to CHD, hypertension is the major risk factor for strokes and congestive heart failure and is a major contributor to renal failure as well. To model the development of strokes and congestive heart failure, the logistic regression models developed in the Framingham Heart study for these outcomes were used.[18] The modeling of hypertensive renal failure has been described earlier.

General Population Mortality Rates

Age-, sex-, and race-specific general population mortality rates were taken from *Vital Statistics of the United States, 1998.*[19]

Discharge From Incarceration

Duration of time in prison is difficult to estimate from available data. Prospective studies of cohorts of inmates from incarceration through discharge and subsequent reincarceration-discharge cycles have not been published. Sentence on admission cannot be used as a proxy for time to be served because actual time served may be substantially shorter or longer. Among prisoners discharged in a given year, information

on time served is available, but these prisoners may not be representative of all those currently incarcerated. Time served varies from State to State and facility to facility. Furthermore, differences exist between those sentenced for violent and nonviolent offenses. After review of several data sources, it was assumed that the average inmate serves 4.5 years and that the distribution of length of stay is exponential. This corresponds to an annual discharge probability of slightly greater than 0.20 and is consistent with Beck et al.[20]

Effects of Treatment

Hypertension is readily treated in the vast majority of compliant patients. The effect of blood-pressure-lowering interventions was modeled by truncating the systolic blood pressure distribution at 140 mmHg when simulating the effects of treatment. This reflects rigorous treatment. As a consequence of the lower blood pressures, the risks of coronary heart disease and renal failure are reduced, and these reductions are reflected in lower counts of those events. Treatment of hypertension was assumed to have no effect on the incidence or progression of complications of diabetes.

Treatment of diabetes has not yet been shown to clearly reduce the incidence of coronary heart disease. It does, however, substantially reduce the risk of microvascular complications and the rate at which they progress.[21] In an analysis of the Diabetes Control and Complications Trial (DCCT), Eastman and colleagues fit a proportional hazards model to the incidence of the various stages of complications. It was found that with tight control of diabetes (HbA1c maintained at 7.2 percent), the relative risk for microalbuminuria is 0.34 and with compared routine diabetic care (HbA1c maintained at 10.0 percent), the relative risk for frank proteinuria is 0.073. With good diabetic control, the relative risk of incidence of each stage of neuropathy is 0.175.[22]

With good diabetic treatment, the progression rates from retinopathy stages R3 and R4 to stage R5 are reduced. Treated annual progression probabilities were taken to be 0.0148 and 0.033, respectively, for all races and all durations of diabetes. (Compare with the rates of progression assumed for untreated diabetes shown in table 10.) For incident background retinopathy, the relative risk is estimated at 0.04; for macular edema, 0.67; and for proliferative retinopathy, 0.126.

Costs of Morbid Outcome Events

When preventive programs such as the one contemplated here are introduced, savings are realized as a result of avoided future morbidity. Although the savings so obtained seldom exceed the outlays necessary to achieve them, they represent a meaningful offset against the total cost of an intervention. Many of the complications of hypertension and diabetes are quite costly, so this offset is appreciable. Table 11 shows the assumed costs for each of the complications modeled.

The costs per person-year of congestive heart failure were estimated by dividing the annual Medicare expenditures for this diagnosis by the number of Medicare patients with the diagnosis.[23] The costs of diuretics and ACE inhibitors were

Table 11. Estimated Unit Costs of Complications of Hypertension and Diabetes

Morbid Event or State	Unit Cost
Person-year with congestive heart failure	$2,188.40
Person-year with a lower extremity amputation	4,808.46
Incident case of coronary heart disease	15,952.00
Person-year of blindness	16,207.00
Person-year with end-stage renal disease	46,207.00
Incident stroke	50,000.00

added to that sum because these are not covered by Medicare or reckoned in their reports. The costs of lower extremity amputation were calculated by amortizing the costs associated with an amputation and subsequent rehabilitation and followup care and over the expected lifespan of amputees.

The costs of incident coronary heart disease and those of a person-year with end-stage renal disease are taken from Eastman et al.;[24] those of a person-year of blindness are taken from Javitt et al.[25] Most published estimates of the costs of stroke exceed $90,000,[26] but costs of lost earnings and productivity figure heavily in those calculations. Because it is assumed that prisoners are not gainfully employed while incarcerated and primarily earn low wages after release, Matchar's lower estimate that excludes these costs was used.[27]

Not all stages of all complications incur costs. Microalbuminuria requires no treatment and is asymptomatic. Consequently no costs were assigned to its presence. The early stages of retinopathy necessitate both surveillance and treatment, but these costs are included in estimating treatment costs for diabetes (see below), so they are not counted again here.

Costs of Screening and Diagnosis

A major advantage of the prison setting for screening is the essential absence of indirect costs. Screening for hypertension and diabetes mellitus in a prison simply requires applying a sphygmomanometer and drawing a blood glucose level during one of the numerous visits made by prisoners each year to the prison physician. Because prisoners are not gainfully employed and are not free to pursue self-selected leisure activities, no opportunity costs attach to their undergoing these tests. Because prisoners average more than 10 physician visits per year (R. Greifinger, personal communication), no additional facilities or service capacity are required to carry out these tests. Some additional expenses will be incurred for repeat blood pressure and blood glucose measurements to confirm abnormal initial results. Overall, however, the average per capita annual cost of screening and confirmatory tests likely will not exceed $15.

Costs of Treatment

To achieve the benefits of treatment, resources must be expended to lower blood pressure and control hyperglycemia. For mild hypertensives, treatment with dietary modifications and exercise is often sufficient to bring about a normal blood pressure. In those requiring medication, adequate treatment can be achieved for almost all hypertensives by using a diuretic plus a beta-blocker. Assuming that the least expensive generic brands of drugs are used, and assuming five physician checkups per year, the annual per capita cost of treating hypertension will be approximately $388.40.[28] Eastman and colleagues have reported the average increased costs associated with aggressive diabetic treatment as $1,983 per person-year.[29] This amount includes the costs of pharmacotherapy with insulin or oral agents, materials for home glucose monitoring, periodic eye examinations, and routine diabetic eye and foot care.

Effects of Treatment on Quality of Life

Although treatment for hypertension often produces side effects, these are less pronounced with modern regimens than they were in the past. No direct effect on quality of life was assumed for treatment of either hypertension or diabetes mellitus. Instead, this effect was reckoned by counting the person-years of less than ideal quality of life avoided when aggressive treatment is used. Table 12 shows the quality-of-life adjustment factors assumed. Detailed studies of quality of life with congestive heart failure are currently being carried out by several investigators.

Table 12. Quality-of-Life Adjustments for Morbid Outcomes of the Analysis	
Complication	**Quality-of-Life Adjustment**
Congestive heart failure	0.9
Status—after lower extremity amputation	0.8
Blindness	0.7
End-stage renal disease	0.6
Status—after cerebrovascular accident	0.5

Congestive heart failure is a heterogeneous condition that can result in minimal impairment or in major disability. The average quality-of-life adjustment factor was estimated to be 0.9, reflecting the preponderance of mild congestive heart failure. The factors for lower extremity amputation, blindness, end-stage renal disease, and cerebrovascular accident were taken from Eastman et al.,[30] Javitt et al.,[31] and Matchar.[32] These figures were used as in the following example: Each person-year of congestive heart failure avoided by treatment results in a gain of 0.1 (=1−0.9) quality-adjusted life-years.

Results

As noted earlier, the effects of screening for and aggressively treating diabetes mellitus and hypertension are manifested in several dimensions: Survival is improved, morbidity is reduced, expenses for screening and treatment are incurred, and savings for treatment of avoided complications are realized. The diverse effects on various types of morbidity, as well as the improvement in survival, can be summarized by enumerating quality-adjusted life-years (QALY) and tallying the expenditures, net of any savings associated with reduced later morbidity. The overall impact may then be summarized as a single number, the cost-effectiveness ratio (CER), defined as:

$$CER = \frac{Costs(\text{with treatment}) - Costs(\text{without treatment})}{QALY(\text{with treatment}) - QALY(\text{without treatment})}$$

Future events and costs are considered less valuable than those in the present. Accordingly, it is conventional, when calculating cost-effectiveness ratios, to discount both the monetary stream in the numerator and the morbidity/mortality stream in the denominator at 3 percent per annum.[33]

Survival and reduction in morbidity

Over 20 years of followup, without screening and treatment, the 1,599,409 persons currently incarcerated are expected to accrue 7,616,668.5 person-years of survival in prison, and an additional 22,567,690 person-years of life outside prison. With aggressive screening and treatment and assuming 100-percent compliance, they will live 7,620,436.5 person-years in prison and 22,950,030.0 person-years outside prison. Thus, screening and treatment have the potential to salvage 386,108 person-years of life for this cohort over 20 years. Of these, more than 99 percent will be lived outside prison. In addition to increased survival, screening and treatment substantially reduce morbidity. Person-years of blindness are reduced by 31,697 with 94.1 percent of this realized outside prison and 61,021 episodes of coronary heart disease are avoided with 91.7 percent of them outside prison. Person-years of congestive heart failure are reduced by 31,555 with 89.25 percent of those outside prison and 44,400 strokes are avoided with more than 90 percent outside prison. Finally, 15,395 person-years of end-stage renal disease are avoided with 94.6 percent of them outside prison.

Expenditures

To achieve these benefits, outlays are made for screening and treatment. Using the cost estimates explained earlier, the total direct cost of screening in this population for 20 years will be $204,817,860. The total costs of hypertension treatment over this same period will be $11,873,569,188. The cost of treatment for

diabetes will be $2,822,545,288. These expenses will be partially offset by the savings from avoided complications. Sixty-three percent of the diabetes screening costs will be incurred outside prison, as will 75 percent of the hypertension treatment costs and 82 percent of the diabetes treatment cost. The proportion of the benefit realized outside prison is still greater.

Cost-effectiveness ratios

When discounting at 3 percent is applied to reflect the distribution of costs, deaths, and morbid events over time, the cost-effectiveness ratio for the screening and aggressive treatment strategy is $11,300 per QALY gained (rounded to the nearest $100). This figure makes this screening and treatment program one of the best investments of health care dollars available. This program would be more cost effective than widely accepted measures such as mammography screening in women age 50–59, or even cervical cancer screening in sexually active women. Except for the assumption of 100-percent compliance, all assumptions have been made conservatively, to bias the costs upward and the benefits downward. The figure of $11,300 per QALY gained is really a cost-efficacy ratio. In the real world, 100-percent compliance will not be achieved.

Modeling partial compliance is problematic. Most noncompliance consists of lapses in adherence or incomplete dosing of medications. Estimates of the extent of these behaviors are hard to acquire. Instead, compliance has been modeled as follows. Noncompliance is assumed not to reduce treatment costs. It is assumed, however, that noncompliance reduces the benefits of treatment by an amount equal to the noncompliance rate. In other words, 80-percent compliance in prison is modeled by recasting the calculations using the full costs of treatment, but recognizing only 80 percent of the in-prison benefit. This noncompliance model would be correct if, for example, the specified fraction of patients made regular physician visits and purchased their medicines, but then discarded them. In reality, noncompliance usually involves skipping some visits and consuming less medication. This starker model of noncompliance overestimates the cost-effectiveness ratio for a treatment plan.

A realistic assumption might be that 80-percent compliance can be obtained while in prison, with 50-percent compliance outside prison. Under this 80/50 compliance assumption, the cost-effectiveness ratio rises to $22,200 per QALY. This still compares favorably with the cost-effectiveness ratios of widely accepted practices.

The assumption that 80-percent compliance can be achieved in prison is reasonable. But because the cost-effectiveness ratio is sensitive to compliance rates, a less favorable scenario was also examined: 50-percent compliance both in and out of prison. The 50-percent compliance rate is widely believed to be obtained outside prison for treatment of hypertension and diabetes. This assumption makes a realistic assessment about compliance out of prison, combined with the assumption that adherence is not improved under conditions of incarceration. This might be regarded as a worst-case scenario. Even in these pessimistically constructed circumstances the cost-effectiveness ratio rises only slightly, to $22,600 per QALY.

Recommendations and Discussion

Limitations

The approach taken in this analysis has limitations. It is a leap of faith to assume that the prevalence of the conditions investigated and their sequelae are properly represented by the relied on sources (primarily NHANES–III and the Framingham study). This leap of faith is necessitated by the lack of studies of the incarcerated population specifically. Putting together estimates of risk-factor prevalence from NHANES–III with prognosis projections from Framingham is also problematic because of partially differing case definitions and the absence of ethnic stratification in the Framingham models.

The analysis also makes simplifying assumptions about the prison population. For example, it is assumed that there is no value to inmates' time while incarcerated and that they will earn low

wages after release. Because suitable statistics about recidivism were not available, it is also assumed that once released from prison they do not return. A better accounting of recidivism would modify the distribution of costs and benefits between the prison system and the community outside prison, but would affect the cost-effectiveness ratios negligibly, if at all. In a related matter, the analysis takes no account of possible additional criminal behavior during the additional years of survival and better health.

The cost estimates used in this analysis are a few years old. Adjustment to 1999 dollars would increase the estimated cost-effectiveness ratios only slightly because health care inflation has been moderate in the past 5 years and none of the estimates are from sources older than that. It has been assumed that annual screening for hypertension and diabetes can be carried out for only $15 per capita by using existing capacity and disregarding indirect costs. This assumption might be excessively optimistic. Some facilities might not currently perform routine blood tests, in which case the incremental costs of screening for diabetes would be higher. Even when the cost-effectiveness ratios are recalculated, assuming $45 per person per year, those ratios only rise by approximately 20 percent.

Finally, the model treats the prison population as essentially homogeneous across jurisdictions and facilities. The age-, sex-, and race-specific prevalence of hypertension and diabetes or the distributions of lipids and smoking may differ by geography or by prison. Although this does not invalidate the overall conclusion, examining such heterogeneity might make it possible to identify target areas that present unusually good opportunities for prevention or other places where a less intensive program might be sufficient.

Recommendations

Using conservative assumptions throughout, the conclusion seems inescapable that annual screening for hypertension and diabetes, followed by aggressive treatment of these conditions, is an excellent investment of health care resources. Hypertension screening and treatment should be carried out in accordance with the recommendations of the Joint National Committee for the Detection, Evaluation and Treatment of High Blood Pressure.[34] Screening for diabetes can be accomplished with a single fasting blood sugar. If the result exceeds 125 mg/dL, a subsequent postprandial blood sugar can be obtained, and a diagnosis made if the result exceeds 140 mg/dL. Subsequent treatment should include "home" glucose monitoring, dietary management, and appropriate use of insulin or oral hypoglycemic agents, with a target HbA1c level of 7.2 percent. Routine diabetic care should include periodic examinations of the optic fundi and the feet.

Most of the costs of the program and an even larger share of its benefits will be incurred outside prison. The results are sensitive to the degree of treatment compliance attained, but even under relatively pessimistic assumptions, the cost-effectiveness ratio still remains a bargain compared with many widely accepted preventive practices.

The United States Preventive Services Task Force's *Guide to Clinical Preventive Services* currently recommends screening for hypertension by taking blood pressure but does not specify a particular frequency. The task force does not currently recommend screening for diabetes. Its recommendation, however, predates the demonstration that aggressive treatment of diabetes substantially reduces complications.[35] It is expected that future editions of the Guide will endorse screening for diabetes mellitus.

Policymakers look beyond cost-effectiveness ratios to other considerations. Some might question the justice of providing state-of-the-art health care to those who have transgressed society's rules while others outside prison lack access to even rudimentary health care. It is also debatable whether providing first-rate health care to prisoners is politically viable in the current climate. To some extent, both of these concerns are mitigated by the observation that the bulk of the impact of the proposed interventions will be attained after prisoners are released, having paid their debt to society and begun contributing to the economy again.

In addition to the recommendations for screening and treatment, it is recommended that the authorities responsible for correctional facilities make health information specific to prisoners available. The simplest way to accomplish this might be to include a sample of prisoners in future iterations of the National Health and Nutrition Examination Survey. Reports on the health status of prisoners will prove invaluable in planning, setting, and evaluating health care policy for this large segment of the U.S. population.

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