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Effectiveness and cost effectiveness of cardiovascular disease prevention in whole populations: modelling study

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Abstract

Objective To estimate the potential cost effectiveness of a population-wide risk factor reduction programme aimed at preventing cardiovascular disease.

Design Economic modelling analysis.

Setting England and Wales.

Population Entire population.

Model Spreadsheet model to quantify the reduction in cardiovascular disease over a decade, assuming the benefits apply consistently for men and women across age and risk groups.

Main outcome measures Cardiovascular events avoided, quality adjusted life years gained, and savings in healthcare costs for a given effectiveness; estimates of how much it would be worth spending to achieve a specific outcome.

Results A programme across the entire population of England and Wales (about 50 million people) that reduced cardiovascular events by just 1% would result in savings to the health service worth at least £30m (€34m; $48m) a year compared with no additional intervention. Reducing mean cholesterol concentrations or blood pressure levels in the population by 5% (as already achieved by similar interventions in some other countries) would result in annual savings worth at least £80m to £100m. Legislation or other measures to reduce dietary salt intake by 3 g/day (current mean intake approximately 8.5 g/day) would prevent approximately 30 000 cardiovascular events, with savings worth at least £40m a year. Legislation to reduce intake of industrial *trans* fatty acid by approximately 0.5% of total energy content might gain around 570 000 life years and generate NHS savings worth at least £230m a year.

Conclusions Any intervention that achieved even a modest population-wide reduction in any major cardiovascular risk factor would produce a net cost saving to the NHS, as well as improving health. Given the conservative assumptions used in this model, the true benefits would probably be greater.

Introduction

Cardiovascular diseases (principally coronary heart disease and stroke) together account for more than 150 000 deaths a year in the United Kingdom.[1] Cardiovascular diseases affect more than five million people, and annual costs exceed £30bn (€34bn; $48bn).[2] However, more than 80% of premature (at age <75) cardiovascular disease is avoidable.[3 4]

The UK government strategy for the primary prevention of cardiovascular disease therefore focuses on a dual approach. National Health Service (NHS) health checks to detect and treat people at high risk are underpinned by policies benefiting the entire population, such as smoke-free legislation and the progressive reduction in the salt content of processed food.[5 6]

In 2004 the Wanless report suggested that a more "fully engaged" population-wide prevention strategy might save £36bn a year.[7] Abelson estimated comparable savings in Australia.[8] More recently, the Trust for America's Health calculated a six for one return on investment for population-wide approaches to prevention in the United States.[9]

Elsewhere, many studies have suggested that tobacco control programmes are cost saving.[10] Likewise, dietary salt reduction policies consistently seem to be very cost effective,[11] or even cost saving.[12 13] However, data on the economics of other population based dietary interventions, such as the eradication of *trans* fats or reduction of saturated fat, are much scarcer.[10-15]

The effectiveness and cost effectiveness of population based dietary approaches to prevention of cardiovascular disease in the UK are less clear. The Department of Health therefore asked

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Extra material supplied by the author (see http://www.bmj.com/content/343/bmj.d4044/suppl/DC1) the National Institute for Health and Clinical Excellence to develop guidance on a public health programme aimed at preventing cardiovascular disease in whole populations. To inform this programme, we built a generic economic model to estimate the comparative cost effectiveness of such interventions. After initial development and testing, we applied this model to two general scenarios involving small decreases in population levels of blood pressure or total cholesterol concentrations and to two specific legislative interventions aimed at reducing the dietary intake of salt and *trans* fats.

Methods

After consultation with stakeholders, we built a generic spreadsheet model quantifying a range of possible interventions, which could estimate cases of cardiovascular disease and deaths due to cardiovascular disease prevented or postponed, life years and quality adjusted life years (QALYs) gained, and cost savings to the NHS resulting from cases prevented or postponed. After initial development and testing, we applied this model to two general scenarios involving small decreases in blood pressure and total cholesterol concentration and to two specific examples of legislative interventions to reduce the dietary intakes of salt and *trans* fats.

Model development

We developed a spreadsheet model in four successive stages: costs, cases prevented, individual benefits, then aggregating the benefits.

Determining NHS costs and QALYs lost for one case of cardiovascular disease

For costing, we adapted the principles of the Sheffield prevention model, updating unit costs and otherwise inflating to 2008.[16] These are detailed in the web appendix. All new costs and inflation indices came from Curtis.[17]

We estimated the expected lifetime costs, life years, and QALYs after a first cardiovascular event as a function of age and sex. Comparing these with life expectancy without an event then gave the loss in life years and QALYs from such an event. For example, we considered the case of a 65 year old man who developed stable angina. We combined life expectancy data from the government actuary's department with quality of life data from Sheffield to estimate a discounted quality adjusted life expectancy of 8.50 QALYs.[16] We used data from Ward et al to estimate lifetime treatment costs with stable angina of £2338 and a loss of 2.12 QALYs.[16] We then did similar calculations for a 65 year old man having a first cardiovascular event to estimate lifetime treatment costs and QALYs lost. The range of cardiovascular events reflected the typical age dependent case mix.[16] We then repeated this process for men and women at all ages from 40 to 90 years (see appendix).

Assessing pattern of cases of cardiovascular disease prevented or postponed for intervention of known effectiveness, using Framingham risk equation applied to single birth cohort

We assessed the pattern of cases prevented or postponed by an intervention of known effectiveness. We used the Framingham risk equations to generate the expected pattern of first cardiovascular events according to the person's age, sex, and risk of cardiovascular disease.[18]

To estimate the effect of an intervention, we used a relative risk applied to the annual risk of a first cardiovascular event. This generated expected reductions in first cardiovascular events over a 10 year period. The appendix shows an example for a 65 year old man with a 10 year risk of cardiovascular disease of 12.5% and an intervention achieving an annual relative risk of 0.9. We then did similar calculations for all men and women in 10 year age bands from 45 to 75. The distribution of risk factors in 10 year age groups was based on the Joint British Societies' guidelines.[19] For ease of modelling, we took the "under 10%" cardiovascular disease risk group at 7.5% and the "over 30%" risk group at 32.5%.

Combining results from first two stages to estimate potential outcomes for single combination of age, sex, and risk

We then combined the results of the first two stages to produce estimates of deaths prevented, life years gained, QALYs gained, and cost savings separately for each group. The appendix shows an illustrative example for an intervention with relative risk 0.9 applied to 65 year old men.

Generating output for men and women of all ages, then aggregating results to give total estimated NHS costs and QALYs gained at level of entire England and Wales population of 50 million

To reflect the nature of the risk equation and the assumptions needed, we conservatively estimated benefits from a reduction in the number of cases over a 10 year time horizon. We then expressed the output on an annual basis. We then aggregated the results across these distributions to give us expected outcomes for men and women of unknown cardiovascular disease risk in 10 year age bands.

We calculated the total population effects for 10 year age groups in England and Wales by using data from the Office for National Statistics.[20] We then calculated the total population without cardiovascular disease eligible for primary prevention by subtracting the Sheffield estimate of the people with a history of cardiovascular disease from the population total.[16] Scaling up the group results then provided the estimates for the total population (see appendix).

We used NICE's standard annual discount rate of 3.5% for both costs and outcomes. We have converted total savings into annual equivalent savings across each of the 10 years, after allowing for the discounting applied. Full technical details of the model are available in the appendix and on the NICE website.[21]

Results

Generic population-wide interventions

Reducing the cardiovascular risk of the population by just 1% sustained over 10 years would prevent approximately 25 000 new cases of cardiovascular disease and 3500 deaths from cardiovascular disease. This would gain around 98 000 QALYs and would generate total (discounted) savings of approximately £265m, equivalent to annual savings across the 10 years of the programme of approximately £30m, compared with no additional intervention (table 1). Here, and elsewhere, a large part of the substantial gain in QALYs is due to the prevention of non-fatal events that strongly affect quality of life. The number of QALYs gained therefore exceeds the number of life years gained.

Reducing population blood pressure levels or total cholesterol concentrations by 5% would result in correspondingly larger health gains. Annual equivalent savings would be approximately

£100 million for blood pressure (table 2) and £80 million for cholesterol (table 3).

Specific interventions

Legislation to reduce salt intake

Dietary salt intake in England and Wales averages approximately 8.5 g/day. A reduction of 3 g/day in salt intake represents a conservative estimate of the potential effects of specific legislation, based on the 6 g reduction achieved in Finland, Japan, and elsewhere.[22] Reducing salt intake by 3 g/day might reduce mean population systolic blood pressure by approximately 2.5 mm Hg.[23] This would equate to a 2% decrease in the risk reduction model.[23] This would prevent approximately 4450 deaths from cardiovascular disease, with total discounted savings overall of approximately £347m over a decade, representing equivalent annual savings of approximately £40m (table 4). Any salt reduction intervention totalling up to £40m a year would therefore still be cost saving.

Legislation to ban industrial fats

Industrial *trans* fats account for approximately 0.8% of total UK dietary energy intake.[23] Based on experience in Denmark, *trans* fat levels could be reduced by approximately 0.5% of total UK dietary energy intake.[15 24] This would reduce the relative risk of death from cardiovascular disease by approximately 6%.[25] Applying these benefits to the entire England and Wales population would prevent approximately 2700 deaths annually and thus gain 570 000 life years, saving the equivalent of approximately £235m a year (table 5). An intervention costing up to £230m a year would therefore still be cost saving if it achieved the desired reduction in *trans* fats.

Sensitivity analyses

We did an extensive series of sensitivity analyses. In brief, savings occurred even when the background risk was reduced by 5% or 50%. Corresponding increases of 5% and 50% are also shown for completeness in the web appendix.

Discussion

Our results strongly suggest that any policy intervention achieving even a 1% population-wide reduction in risk of cardiovascular disease can be expected to produce a net cost saving to the NHS, as well as decreasing losses in productivity and improving health. Only if a very large sum of money needs to be spent on implementing the legislation would this cease to be the case. Our findings are reassuringly consistent with analyses from the United States, Australia, and the UK Treasury.[7-15 26] Likewise, a five year campaign on salt reduction by the UK Food Standards Agency cost approximately £15m and achieved a reduction of 0.9 g/day in average salt intake. This was estimated to prevent approximately 6000 cardiovascular deaths a year, with estimated savings totalling some £1.5bn, or £300m a year.[6] Furthermore, analyses of cohorts with lower cardiovascular risk show fewer cardiovascular events delayed to an older age and incurring substantially lower Medicare costs.[27]

The 5% reductions modelled for systolic blood pressure and cholesterol concentration are entirely consistent with the actual falls achieved in regional programmes such as North Karelia, Stanford, and HeartBeat Wales.[28 29] Furthermore, much larger reductions in entire populations have been documented since the 1980s. For instance, cholesterol reductions of 22% in Finland, 14% in Iceland, 10% in Sweden, and 6% in the United States have been reported.[30 31 32 33] Likewise, blood pressure reductions of 8% in England and 6% in Finland have been reported.[29 30]

Our 0.5% reduction in industrial *trans* fats represents a conservative estimate of what is possible, given past UK trends and recent Danish experience of successful eradication.[34] Industrial *trans* fats have now been banned in five European countries: Denmark, Switzerland, Austria, Sweden, and Iceland. Manufacturers have adapted rapidly, easily, and with minimal costs.[35] We would suggest that the UK is unlikely to be very different. Furthermore, important inequalities exist, given the very high consumption of *trans* fats recently reported in some disadvantaged groups (exceeding 6% of daily energy).[35] Benefits in deprived communities might therefore be even larger.

Strengths of analysis

Our spreadsheet model allows a relative risk to be applied to each year's risk of primary cardiovascular disease in the population. It also allows percentage reductions in cholesterol concentration and systolic blood pressure to be considered separately for men and women. The model is designed to be transparent and involves relatively few assumptions, each of which can be easily tested. Furthermore, the estimates are based on a series of conservative assumptions, so the true benefits are likely to be substantially larger.

We quantified only NHS savings. Net social savings will clearly be much larger. The model focuses on primary prevention of cardiovascular disease. All population-wide risk factor reduction programmes considered in this report would also benefit the five million patients with recognised cardiovascular disease in the UK.[36 37] Substantial reductions in diabetes, many common cancers, and other chronic diseases would also occur.[37]

This simple model assumed a uniform distribution of burden and benefit across social groups. In fact, deprived groups have disproportionately more disease and would thus gain more from population-wide risk factor reductions. Absolute inequalities would also be decreased.[38]

This is not simply a cost of illness study. It is a modelling study that shows the range of possible cost savings and QALY benefits from a range of plausible interventions. It therefore allows an upper limit to be placed on the cost at which any such intervention would be worthwhile. Greater complexity in the model might lead to additional precision in the results. However, we suggest that this additional precision might make surprisingly little difference to the key policy decisions.

The sensitivity analyses were reassuring and suggested that using a different risk "engine" to drive the model would have a relatively modest effect. The model is based on the original Framingham equations and the same risk score as the Joint British Societies' guidelines, which is widely used and understood. It also reflects the model that was presented to the NICE Programme Development Group to assist in their deliberations and inform their subsequent key recommendations.[35]

Limitations of analysis

Our conclusions are clearly subject to several important limitations reflecting the nature of the model. Apart from the increased mortality immediately after a first non-fatal primary cardiovascular event, we made no attempt to consider recurrent events or subsequent deaths. The estimates of deaths avoided, life years gained, and cost savings are thus likely to be underestimates, making the analysis somewhat conservative. A further limitation is the 10 year time frame for prevention of cases; gains over a lifetime would clearly be greater.

The analysis was pragmatically limited to people aged between 40 and 79 years at the time of the intervention. However, given the very high rates of cardiovascular events in people aged over 80, substantial additional benefits might be expected. Our interventions assumed relatively uniform effects across age and risk groups by definition. However, the subsequent changes in specific risk factors included age gradients and considered men and women separately.

In this study, the counterfactual (no intervention) implicitly assumes that the population risk of cardiovascular disease would remain constant. However, there may be a "natural" increase or decrease in cardiovascular risk without population-wide interventions. Modest changes could also follow targeted interventions in subgroups. Either of these scenarios might affect future costs and QALYs.

Finally, this initial modelling lacks a full probabilistic sensitivity analysis, because many essential data inputs (such as the distribution of risk factors in the population) were readily available only as point estimates. However, the range of changes in risk factors and their effects quantified in the results tables and web appendices provide a satisfactory and rigorous sensitivity analysis. Future studies might usefully include a full probabilistic sensitivity analysis to formally test the uncertainties inherent in the various modelling assumptions.

Implications of findings

We estimated that a 1% reduction in the relative risk of cardiovascular disease would generate discounted NHS savings of approximately £30m a year in England and Wales, compared with no additional intervention, This estimate is considerably less than 1% of the £7bn healthcare costs calculated by Luengo-Fernández et al.[2] However, this again highlights the conservative approach taken in our modelling.

In terms of opportunity cost, any programme that reduces the rate of death from cardiovascular disease by 1% is cost effective up to costs of £30m, as long as no alternative programme causes a bigger reduction at the same costs or the same reduction at lower costs. Varying the underlying Framingham risk equation to include newer values such as $QRISK_2$ will also be useful.[39] However, the resulting changes are likely to be small. Furthermore, subsequent research should ensure that such models remain up to date, accessible, and credible. A better quantification of our understanding of causal pathways for cardiovascular disease will be challenging but important.

An important factor is the feasibility of population-wide dietary changes—for instance, in salt consumption. Cultural aspects are important in some countries, such as salted fish in Portugal and salted vodka further east. However, most populations now live in a global economy. We eat what is available, affordable, and acceptable. In our UK study population, that means that more than 80% of consumed salt is concealed in processed food.[22 35] In the UK, media campaigns and voluntary agreements with the food industry have already achieved a 1 g reduction in salt consumption. We therefore suggest that a 3 g reduction might be entirely feasible by using more muscular regulatory approaches. The 6 g reductions in Finland and Japan were achieved in spite of cultural traditions and resistance from the industry.[22 29] Furthermore, reductions of 5-10% in the salt content of any specific food during one year are simply not noticed by most consumers. This is because human taste buds adapt very quickly. Salt has already been substantially decreased in the UK and several other countries, with no evidence of widespread compensation by consumers.[35]

This paper does not detail the specific costs of particular programmes. It is making a more general argument. Given the benefits in terms of increased health and reduced healthcare costs, the sorts of programmes we have seen work in other countries must surely also be cost effective here.

Conclusions

Our model is relatively simple and transparent with clear limitations. However, the cumulative conservative assumptions mean that the benefits and cost savings are almost certainly underestimated. The findings are reassuringly consistent with results from very different methods in the United States, Australia, and the UK Treasury.[7-9 26 27 40] Population-wide prevention interventions seem to be both powerful and cost saving.

Contributors: PB and LA designed and implemented the model with advice from KMcP, AB, and SC. SC drafted the first and final versions of the manuscript and led the submission and revision process. All authors contributed to the drafting and approval of the final manuscript. PB is the guarantor.

Funding: PB and LA were funded by NICE. KMcP, AB, and SC were all members of the NICE Programme Development Group on cardiovascular disease prevention in populations. However, the conclusions do not necessarily reflect official NICE views. West Midlands Health Technology Assessment Collaboration (WMHTAC) and Peninsula Technology Appraisal Group (PenTAG) were funded to provide support to the NICE Centre for Public Health Excellence (CPHE).

Competing interests: All authors have completed the Unified Competing Interest form at www.icmje.org/coi_disclosure.pdf (available on request from the corresponding author) and declare no support from any organisation apart from NICE for the submitted work. PB and LA were funded by NICE. WMHTAC and Peninsula Technology Appraisal Group (PenTAG) were funded to provide support to the NICE CPHE. KMcP, AB, and SC were all members of the NICE Programme Development Group on CVD prevention in populations.

Ethical approval: Not needed.

Data sharing: No additional data available.

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What is already known on this topic

Population-wide prevention programmes, such as salt reduction, *trans* fat eradication, or smoke-free legislation seem to be very effective for preventing cardiovascular disease

Studies in the United States and Australia suggest that as well as reducing cardiovascular events and deaths, such programmes may also be cost saving

What this study adds

A national programme reducing population cardiovascular risk by 1% would prevent approximately 25 000 cardiovascular disease cases and generate public sector savings of about £30m a year

Reducing mean population cholesterol or blood pressure levels by 5% (as already achieved in some other countries) would result in annual savings of approximately £80m or £100m

Legislation or other measures to reduce dietary salt intake by 3 g/day or industrial *trans* fatty acid intake by approximately 0.7% of total energy content would save about £40m or £230m a year

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Accepted: 13 May 2011

Cite this as: *BMJ* 2011;343:d4044

Tables

Table 1| Discounted outcomes for intervention achieving given relative risk reduction sustained over 10 years

Relative risk reduction	Cases prevented (×1000)	Deaths prevented (×1000)	Life years gained (×1000)	QALYs gained (×1000)	Total savings (£m)	Annual equivalent savings (£m)
0.001	2	0.3	7	10	26	3
0.005	12	1.7	37	49	132	15
0.01	25	3.5	74	98	265	31
0.02	50	7.0	149	197	530	62
0.03	75	10	224	295	796	93
0.04	100	14	299	394	1063	123
0.05	125	18	374	493	1330	154
0.06	150	21	449	592	1597	186
0.07	175	25	524	692	1865	217
0.08	201	28	600	791	2133	248
0.09	226	32	675	891	2402	279
0.1	251	35	751	990	2671	310
0.15	378	53	1132	1492	4024	467
0.2	507	71	1516	1997	5389	626
0.25	637	89	1903	2507	6766	786
0.3	768	108	2294	3021	8155	947
0.35	900	126	2689	3540	9557	1110
0.4	1033	145	3088	4062	10 971	1275
0.45	1168	164	3490	4589	12 397	1440
0.5	1304	183	3895	5121	13 836	1607

QALY=quality adjusted life year.

Table 2| Discounted outcomes for intervention with given percentage reduction in systolic blood pressure sustained over 10 years

Percentage reduction in systolic blood pressure	Cases prevented (×1000)	Deaths prevented (×1000)	Life years gained (×1000)	QALYs gained (×1000)	Total savings (£m)	Annual equivalent savings (£m)
0.5	8	1.1	24	33	86	10
1	16	2.2	48	65	173	20
1.5	24	3.3	72	98	260	30
2	32	4.4	96	131	347	40
2.5	40	5.5	121	164	435	50
3	48	6.7	145	197	522	61
3.5	57	7.8	169	230	610	71
4	65	8.9	194	263	699	81
4.5	73	10.0	219	296	787	91
5	81	11.2	243	330	876	102

QALY=quality adjusted life year.

Table 3| Discounted outcomes for intervention with given percentage reduction in cholesterol concentration sustained over 10 years

Percentage reduction in cholesterol	Cases prevented (×1000)	Deaths prevented (×1000)	Life years gained (×1000)	QALYs gained (×1000)	Total savings (£m)	Annual equivalent savings (£m)
0.5	6	0.9	19	26	68	8
1	13	1.7	38	51	136	16
1.5	19	2.6	57	77	205	24
2	25	3.5	76	103	274	32
2.5	32	4.4	95	129	343	40
3	38	5.3	114	155	412	48
3.5	45	6.1	134	181	481	56
4	51	7.0	153	208	551	64
4.5	58	7.9	172	234	621	72
5	64	8.8	192	260	691	80

QALY=quality adjusted life year.

Table 4| Discounted estimates of total population effects from reduction of 3 g/day in salt intake sustained over 10 years, by age and sex

Age groups (years)	Cases prevented (×1000)	Deaths prevented (×1000)	Life years gained (×1000)	QALYs gained (×1000)	Total savings (£m)	Annual equivalent savings (£m)
Men:						
40-49	4.4	0.51	12	21	47	5
50-59	4.9	0.71	16	21	53	6
60-69	4.8	0.74	15	17	49	6
70-79	3.1	0.45	7	8	28	3
Women:						
40-49	4.0	0.39	11	19	48	6
50-59	3.8	0.51	13	18	46	5
60-69	3.9	0.64	14	16	45	5
70-79	3.2	0.48	9	10	31	4
Totals	32.2	4.43	96	131	347	40

Any apparent anomalies with addition are due to rounding effects.

QALY=quality adjusted life year.

Table 5| **Discounted estimates of total population effects from intervention based on legislation against trans fats sustained over 10 years, by age and sex**

Age groups (years)	Cases prevented (×1000)	Deaths prevented (×1000)	Life years gained (×1000)	QALYs gained (×1000)	Total savings (£m)	Annual equivalent savings (£m)
Men:						
40-49	23	2.7	64	107	243	28
50-59	30	4.3	96	129	322	37
60-69	33	5.1	100	119	335	39
70-79	23	3.3	51	57	200	23
Women:						
40-49	19	1.9	53	92	234	27
50-59	20	2.7	68	94	239	28
60-69	23	3.7	82	95	261	30
70-79	21	3.1	58	61	199	23
Totals	191	26.8	571	754	2033	235

QALY=quality adjusted life year.

Any apparent anomalies with addition are due to rounding effects.