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Increased intake of fruit and vegetables: estimation of impact in terms of life expectancy and healthcare costs†

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Abstract

Objectives: There is strong evidence that a high consumption of fruit and vegetables reduces the risk of developing many cancers. This study examined the economic consequences for the healthcare sector if people followed the recommendations and increased their intake of fruit and vegetables.
Design: A life table was used to describe a base case population with respect to life expectancy, cancer incidence and healthcare costs. Relative risks of cancer for a high versus a low intake of fruit and vegetables were obtained from the literature and were used to simulate populations with a higher intake of fruit and vegetables. The empirical data consist of a 20% sample of the Danish population that was followed from 1993 to 1997. Civil registration numbers were used to link various computerised registers, in order to describe each individual in the sample in terms of morbidity, mortality and healthcare costs.
Results: The average daily intake of fruit and vegetables was assumed to be approximately 250 g for the general Danish population. Simulated intakes of 400 g and 500 g increased the life expectancy by 0.8 and 1.3 years, respectively. In addition, it was estimated that 19% and 32% of the cancer incidence could be prevented. The aggregate healthcare costs remained stable, as the resources saved due to a lower cancer incidence were offset by healthcare costs imposed by the fact that healthy people live longer and require more healthcare. However, the variations across age groups and health sectors were substantial.
Discussion: The study adopted a healthcare sector perspective. Only costs from hospitalisation and primary care were included in the calculations. The costs of changing people's dietary habits, i.e. education, information and promotion as well as other costs that would be relevant from a societal perspective, have not been taken into account. Furthermore, the transition from one level of intake to another is not the focus of the analysis, although it might take decades to observe the full effect of the dietary changes.
Conclusion: Empirical evidence suggests that a considerable fraction of all cancer incidences can be prevented by a higher intake of fruit and vegetables. That may result in improved public health (gain in life years) at no additional cost to the healthcare sector.

Keywords
Fruit
Vegetables
Cancer
Healthcare
Costs

Cancer is largely a preventable disease. A variety of lifestyle factors, including smoking, alcohol, overweight and dietary habits, influence the risk of contracting cancer. In the early 1980s, Doll and Peto[1] estimated that between 10 and 70% of all cancer cases in the USA could be related to diet. Fruit and vegetables stand out as being important factors in the protective effects of the diet, and a number of reviews have provided evidence that a diet high in fruit and vegetables decreases the risk of developing many cancers. Van't Veer *et al.*[2] reviewed more than 200 epidemiological studies to quantify the protective effects of a high intake of fruit and vegetables. These foods appeared to have a significant influence on the risk of many cancer sites – especially for gastrointestinal cancers and to some degree for hormone-related cancers. The authors estimated relative cancer risks for three scenarios (best guess, optimistic and conservative) that depended on the strength of the underlying assumptions.

The fact that fruit and vegetables decrease the risk of

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cancer has been the inspiration for policy initiatives in countries all over the world. Campaigns have been established to influence the dietary habits of populations and to improve public health[3–5]. The outcomes of such campaigns are not well documented. The aim of this study was to examine the health economic consequences that might result if people followed the dietary recommendations from the campaigns and increased their intake of fruit and vegetables, such that a lower number of cancer cases would occur.

Predicting the health economic consequences for the healthcare sector is not straightforward, as different effects work in different directions and might offset each other. Healthcare resources are saved when fewer people get cancer. However, the extra life years that are gained will increase costs, since old age is an important determinant for the consumption of healthcare resources. Bonneux *et al.*[6] found that an elimination of fatal diseases such as cancer would increase expected lifetime healthcare costs, because additional medical expenses would be incurred during the added life years. Nusselder *et al.*[7] found that the elimination of cancer would lead to a relative expansion of morbidity.

An increased intake of fruit and vegetables alone will not eliminate cancer, but will reduce the incidence. The aim of this study was to investigate further the quantitative effects of an increased intake of fruit and vegetables on healthcare resources and life expectancy.

Methods

Life table

A period life table for 1997 was used to describe the base case population with respect to life expectancy, cancer-free life expectancy, cancer incidence and healthcare costs. A life table is a static model that utilises the mortality of a population over a short period of time to create a synthetic cohort from which life expectancy can be calculated. The life table model was extended to include two states: a healthy state and a state with cancer. Events such as cancer or death determined the switch from one state to another. The state with cancer was further divided into 13 different types of cancer. The model that was used here allowed for only one type of cancer per person. After the first cancer diagnosis, therefore, the individual was included in the prevalence of that particular type of cancer until death or censoring.

Age-specific risks of death, risks of cancer and risks of dying with a diagnosis of cancer were calculated from the 1997 sample population, using actuarial methods that took censoring into account. These risk estimates were used to create a cause-eliminating life table, from which baseline life expectancy, cancer-free life expectancy, cancer incidence and aggregate healthcare costs could be calculated. The healthcare costs were entered into the life table through the assignment of age- and disease-specific mean costs to the synthetic cohort.

Table 1 Risk ratios for an increase in fruit and vegetable intake from 250 to 400 g day^{-1}*

	Best guess	Optimistic	Conservative
Upper respiratory tract			
Oral cavity, pharynx	0.52	0.47	0.57
Larynx	0.45	0.40	0.50
Lung	0.58	0.46	0.65
Gastrointestinal			
Oesophagus	0.54	0.46	0.61
Stomach	0.49	0.43	0.59
Colon/rectum	0.63	0.53	0.74
Hormone-related			
Breast	0.84	0.68	0.96
Endometrium	0.78	0.60	1.00
Prostate	0.93	0.78	1.00
Other			
Pancreas	0.62	0.43	0.75
Bladder	0.65	0.56	0.74
Kidney (renal cell)	0.80	0.75	0.85

* Review study by van't Veer *et al.*[2].

Data on fruit and vegetable intake were only available at aggregate level. The average intake of fruit and vegetables was assumed to be approximately 250 g day^{-1} for the base case population. Relative risk estimates from van't Veer *et al.*[2] ('best guess' scenario) were used to lower the risks of dying and the risks of cancer in the event of an increased average intake (Table 1). The relative risks were assumed to be applicable to all age groups. The interdependence between risks of different types of cancer was taken into account by an approximation, as decreasing the risk of developing one type of cancer will increase the risk of developing another or of dying from a different cause. The baseline case was repeated with average intakes of 400 and 500 g day^{-1}. The risk reductions for the higher intake were linearly extrapolated, as only risk reductions for 400 g day^{-1} were available.

The differentials between the baseline case and the situations with the new higher intakes were interpreted as the health effects for the population and the costs for the healthcare sector. Such a comparative static analysis does not consider the transitions from one situation to another. The life tables were interpreted as stationary populations and, in accordance with Bonneux *et al.*[6], neither the costs nor the health effects were discounted.

One-way sensitivity analyses were conducted to examine the robustness of the model. After the 'best guess' estimates had been used, the effects were recalculated using the optimistic and conservative estimates of the relative risks. In addition, the risks of events were modified with percentage changes.

Data sources

The data consisted of a 20% random sample of the Danish population that was followed from 1993 to 1997

($n = 1\,034\,289$ people). In order to describe each individual in the sample in terms of morbidity, mortality, healthcare costs and socio-economic variables, unique personal civil registration numbers were used to link computerised registers held at Statistics Denmark and the Danish Cancer Registry.

Morbidity data were obtained from the Cancer Registry, which covers all cancer cases in Denmark since 1943. Data on the time and cause of death were drawn from the Registry of Causes of Death.

Healthcare costs were defined in terms of hospitalisation costs and outpatient treatment costs. Hospitalisation costs were obtained from the National Patient Register. Each hospital admission between 1993 and 1997 was described by an estimated charge based on the Danish case mix system of Diagnosis Related Groups (DRGs). The case mix system covers inpatient hospital stays, while ambulatory and emergency room visits are described by a similar, but more simple, system. Costs of primary care were determined from reimbursement fees for visits to general practitioners, physiotherapists, dentists and specialists. Psychiatric treatments, reimbursements for pharmaceuticals and capital costs were not included in the estimates of healthcare costs.

Results

The radix of the life table was chosen to be 67 000, which was the birth rate in Denmark in 1997. Although the calculations of life expectancy are independent of the radix, this number of newborns was selected to create a cohort similar to the Danish population.

In the base case, life expectancy was estimated to be 75.7 years. This is close to the official 1997 Danish life expectancy figures of 73.4 and 78.7 years for men and women, respectively[8]. Of this life expectancy of 75.7 years, 73.5 years could be attributed to cancer-free life expectancy.

The modelled effects of a higher average fruit and vegetable intake can be seen in Table 2. When the calculations were repeated with average intakes of 400 and 500 g day^{-1}, the life expectancy increased by 0.8 and 1.3 years, respectively. The cancer-free life expectancy increased by even more: 1.1 years for an intake of 400 g day^{-1} and 1.9 years for 500 g day^{-1} (the apparent inaccuracy is caused by rounding). The rest of the data in Table 2 are dependent on the chosen radix, but it is the relative magnitudes that are important here. The data give an impression of the quantitative effects on cancer prevalence and incidence for a country like Denmark.

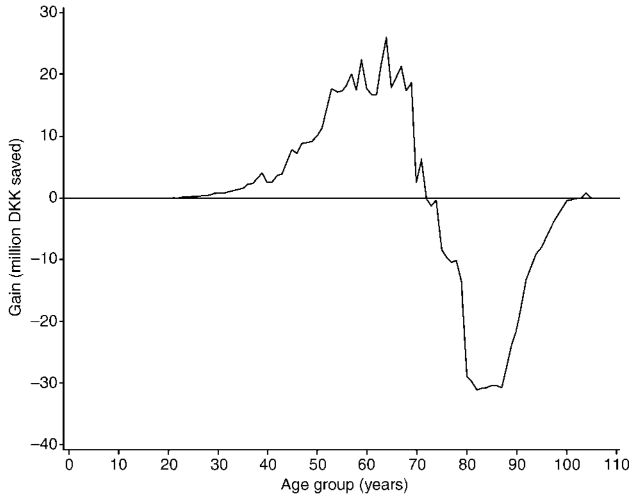

Fig. 1 Net gains in healthcare costs across age groups for an increased intake of fruit and vegetables

The aggregate healthcare costs were seemingly unaffected by the lower number of cancer cases as a result of a higher intake of fruit and vegetables (approximately 0% of the total healthcare costs). This result is the outcome of several offsetting effects. Across age groups and healthcare sectors, there were substantial changes. When the disease-specific mean costs were held constant for each age group, the number of people as well as the distribution of cancer and non-cancer cases changed for each age group as the intake of fruit and vegetables increased. Figure 1 shows the net changes in costs across age groups. For age groups up to approximately 70 years of age, the costs were lower due to fewer cancer cases. But since healthier people live longer, there were more people in the older age groups,

Table 2 Consequences of fruit and vegetable intake

	Daily intake		
	250 g day^{-1}	400 g day^{-1}	500 g day^{-1}
Life years	5 070 014	5 121 141	5 157 231
Life years without cancer	4 922 645	4 997 612	5 050 932
Life years with cancer	147 369	123 529	106 299
Cancer incidence	22 312	18 157	15 098
Cancer-free deaths	44 686	48 840	51 899
Life expectancy (years)	75.7	76.4	77.0
Cancer-free life expectancy (years)	73.5	74.6	75.4

Best guess estimates for 400 g day^{-1}.
Linear extrapolation of estimates for 500 g day^{-1}.

Table 3 Healthcare costs in 1997 as estimated by the life table

	Base case	After simulation	Sum of positive net gains	Sum of negative net gains	Total gain in costs
Hospital costs	22 506	22 374	490	−358	132
Primary care	6 095	6 224	0	−130	−130
Total costs	28 601	28 599	449	−447	2

Net gains are defined as differentials in age-related costs.
Simulated intake is $500\,\mathrm{g\,day}^{-1}$ (best guess estimates).
Costs are given in million DKK, 2000 price level.

and that resulted in more healthcare spending. The cost components are also shown in Table 3, in which the net cost gains across age groups are summed for positive and negative gains (equivalent to the peak and trough in Fig. 1).

The results appeared to be robust to changes in the parameters. However, using conservative relative risks and an intake of $400\,\mathrm{g\,day}^{-1}$, the gains were obviously expected to be somewhat smaller. Under this scenario, the gain in life expectancy would be 0.6 years, with 0.8 cancer-free years. The costs would increase by 0.08%, which is still negligible (see Appendix).

Discussion

As this study adopted a healthcare sector perspective, only costs from hospitalisation and primary care were included in the calculations. Had the perspective been societal, additional costs should have been included, e.g. the costs of care of the elderly, costs of lost production, and tangible as well as intangible costs for the citizens. The costs of intervention have also been ignored. For a full economic evaluation, e.g. a cost-effectiveness analysis, the costs of changing people's dietary habits should also have been included. These would include the costs of education, information and promotion, as well as price subsidies or VAT cuts. The difficulty with this is that the relationship between health promotion campaigns and people's dietary habits is not well known.

The gains from intervention have been measured in terms of the number of life years saved. Since cancer is a disease that can be associated with considerable pain and suffering, it would have been appropriate to adjust the gains in life years for quality of life. A second best solution has been used here, where gains in cancer-free life expectancy are reported along with changes in life expectancy.

While the focus of this study has been on cancer, it may be that this perspective is too narrow. It is likely that a higher intake of fruit and vegetables would also influence the risk of developing other diseases, such as cardiovascular disease, diabetes and obesity. Furthermore, people surviving due to a higher intake of fruit and vegetables might live healthier lives and therefore incur lower costs than predicted by the age- and disease-specific mean costs. While the evidence is not as strong as for cancer, some estimates of the relative risks of mortality caused by cardiovascular diseases are available from van't Veer *et al.*[2]. With respect to gains in life expectancy, a cause-eliminating life table for death from coronary heart disease and stroke showed results that were less pronounced than those for cancer. Changes in healthcare costs due to cardiovascular diseases were not calculated, however, since the estimates of relative risks were only available for mortality and not morbidity.

People were modelled to have only one type of cancer – the first cancer diagnosed. This assumption reduces the complexity of the model. The simplification is likely to result in an underestimation of serious types of cancer developing from other milder types of cancer, and healthcare costs allocated to the wrong cancers (milder cancers). However, at an aggregate level, all costs were included in the model and the deviations are expected to even out.

The present study has taken the form of a comparative static analysis in which two situations are compared: a base case and a situation with an assumed higher intake of fruit and vegetables. Transitional periods were completely ignored and the new equilibrium with a higher intake is assumed to establish itself instantaneously. In reality, when policy initiatives are under consideration, it has to be taken into account that the length of transition periods can be considerable. There is induction time for the tumour to develop and further time before a tumour can be diagnosed. Furthermore, it is not plausible that the dietary habits of a population can change instantly. It might in fact take decades before the gains are noticeable[3]. In addition, the 1997 population might not be representative for future populations with respect to factors such as population distribution, occupational and lifestyle hazards, morbidity and mortality.

The relative risks that were used in this study were taken from van't Veer *et al.*[2]. These authors used more than 200 observational studies to quantify the protective effects of a diet high in fruit and vegetables, and adjusted these to the average intake of the Dutch population. The benefit of using such a review study is that the estimates are based on an array of studies, making the evidence more reliable. The disadvantage is that it is not always clear exactly what assumptions and study designs the estimates are based on. Furthermore, the results of more recent cohort studies[9–11] suggest that the evidence may be weaker than proposed by van't Veer *et al.*[2]. The results from this paper should

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therefore be interpreted with caution and, if necessary, with more emphasis on the results that are based on the conservative estimates.

The relative risks were only available at aggregate level with respect to age. Therefore the relative risks are assumed to be constant by age. At old ages, where the risk of cancer is high, the risk reduction is likely to be overestimated. Adjusting the relative risks to age would most likely reduce the gains in life expectancy a little, whereas the cost savings could go in both directions due to offsetting effects.

It is still controversial whether healthcare costs arising in life years gained should be included in the analysis as a basis for decision-making. It can be argued that if the objective is to increase the number of life years, then the costs of achieving this goal, apart from the intervention costs, are not relevant for the question of whether the policy initiative is a good investment or not. On the other hand, it can be argued that if the costs of the increased number of life years are in fact caused by the intervention, then they ought to be included[12]. Furthermore, the exclusion of these costs can bias decisions in favour of increases in life expectancy at the expense of quality of life[13]. While the current study did not include calculations of intervention costs, it did include costs attributable to a lower number of cancer cases and to added life years. Nevertheless, calculating the different cost components is a complicated task, since the saved cancer cases as well as the added life years occur in all age groups, and this is a different breakdown of costs than that depicted in Fig. 1. If the costs of added life years were ignored, then there is no doubt that a higher population intake of fruit and vegetables would considerably reduce the costs to the healthcare sector.

Conclusion

The results suggest that a higher intake of fruits and vegetables can increase life expectancy by a year or more, and thus improve the health of the population. Such an improvement would only have a modest effect on aggregate healthcare costs, however. The results depend on a number of assumptions and estimates, but the overall result appears to be robust to changes and violations of these estimates and assumptions.

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Appendix – Consequences of fruit and vegetable intake

	Daily intake		
	250 g day^{-1}	400 g day^{-1}	500 g day^{-1}
Optimistic risk reductions			
Life years	5 070 014	5 139 244	5 188 823
Life years without cancer	4 922 645	5 028 358	5 104 425
Life years with cancer	147 369	110 886	84 398
Cancer incidence	22 312	16 457	12 036
Cancer-free deaths	44 686	50 540	54 960
Life expectancy (years)	75.7	76.7	77.4
Cancer-free life expectancy (years)	73.5	75.1	76.2
Costs (million DKK)	28 601	28 589	28 583
Best guess risk reductions			
Life years	5 070 014	5 121 141	5 157 231
Life years without cancer	4 922 645	4 997 612	5 050 932
Life years with cancer	147 369	123 529	106 299
Cancer incidence	22 312	18 157	15 098
Cancer-free deaths	44 686	48 840	51 899
Life expectancy (years)	75.7	76.4	77.0
Cancer-free life expectancy (years)	73.5	74.6	75.4
Costs (million DKK)	28 601	28 600	28 599
Conservative risk reductions			
Life years	5 070 014	5 107 371	5 132 955
Life years without cancer	4 922 645	4 973 124	5 007 930
Life years with cancer	147 369	134 247	125 025
Cancer incidence	22 312	19 494	17 507
Cancer-free deaths	44 686	47 503	49 490
Life expectancy (years)	75.7	76.2	76.6
Cancer-free life expectancy (years)	73.5	74.2	74.7
Costs (million DKK)	28 601	28 624	28 639

Linear extrapolation of estimates for 500 g day^{-1}.

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