There is considerable controversy over the protective effect of diets rich in fruit, vegetables and fibre, and the respective roles of the different components (including micronutrients such as folate). The report of the Committee on Medical Aspects of Food Nutrition Policy (COMA) (Department of Health, 1998) recommended increasing consumption of all of them, an advice that seems to have motivated the Department of Health in promoting its ‘5-a-day’ programme (Department of Health, 2005). The original consensus of the probable decrease in risk of several cancers of the gastrointestinal tract (oral cavity and pharynx, oesophagus, stomach and colorectum) associated with increased consumption of fruit and vegetables (WHO/FAO, 2003) was based on the results of multiple case–control studies and a few prospective studies. The IARC Handbook of Cancer Prevention (IARC, 2003) concludes its review of the evidence as follows:

There is 
limited evidence 
for cancer-preventive effect of consumption of fruit and vegetables for cancers of the mouth and pharynx, oesophagus, stomach, colorectum, larynx, lung, ovarian (vegetables only), bladder (fruit only) and kidney.

There is 
inadequate evidence 
for a cancer-preventive effect of consumption of fruit and vegetables for all other sites.

More specifically, this evidence indicates that higher intake of fruit probably lowers the risk of cancers of the oesophagus, stomach and lung, while higher intake of vegetables probably lowers the risk of cancers of the oesophagus and colorectum.

Likewise a higher intake of fruit possibly lowers the risk of cancers of the mouth, pharynx, colorectum, larynx, kidney and urinary bladder. An increase in consumption of vegetables possibly reduces the risk of cancers of the mouth, pharynx, stomach, larynx, lung, ovary and kidney.

The conclusions of the WCRF report (2007) are more or less in line with these, except with respect to large-bowel cancer, for which the evidence for protective effects of both vegetables and fruit was considered ‘limited’ (in contrast to ‘conclusive’ or ‘probable’ – implying that a causative relationship is uncertain). More emphasis was placed on the importance of the protective effects of consumption of foods containing dietary fibre than on vegetables per se. The summary conclusions were as follows:

Non-starchy vegetables probably protect against cancers of the mouth, pharynx, and larynx, and those of the oesophagus and stomach. There is limited evidence suggesting that they also protect against cancers of the nasopharynx, lung, colorectum, ovary, and endometrium.

Fruit in general probably protects against cancers of the mouth, pharynx, and larynx, and those of the oesophagus, lung, and stomach. There is limited evidence suggesting that fruit also protects against cancers of the nasopharynx, pancreas, liver, and colorectum.

In this analysis, we follow the WCRF in considering ONLY the effect of a deficit of fruit and vegetables on cancers of the mouth and pharynx, oesophagus, stomach and larynx, and of a deficit of fruit on cancers of the lung.

The advice from the Department of Health (2005) is to increase the average consumption of a variety of fruit and vegetables to at least five portions per day, corresponding to 5 x 80 or 400 g per day. In this section, we estimate the population-attributable fraction (PAF) of these five cancers (and of all cancer) that results from consumption of fruit and vegetables lower than this target.

METHODS

The risks associated with consumption of 1 g per day of fruit or of vegetables are shown in Table 1. As we are concerned with quantifying the effect of a deficit in consumption, they are presented as the risk associated with a decreased intake of 1 g per day.

These risks derive from the simple means of the values from three meta-analyses: those of Riboli and Norat (2003), WCRF (2007) and, except for laryngeal cancer, Soerjomataram et al (2010). (The value for the protective effect of vegetables on cancers of the oral cavity and pharynx in the meta-analysis of Soerjomataram et al (2010) was quite implausible, implying a reduction in risk of 1.4% per gram per day. We substituted the value for upper aero-digestive tract cancers from the multi-centre...
European prospective study (EPIC) of 0.29% per gram per day (Boeing et al., 2006)). The values from the latter were reported as relative risk per gram increase in daily consumption of fruit and vegetables. For the others, the excess relative risk for a decrease of 1 g of vegetables or fruit consumed was estimated by assuming a log-linear relationship between exposure and risk, so that:

\[
\text{Risk per gram per day} = \frac{\ln(1/RR_x)}{x}
\]

where \(x\) is the exposure level (in grams per day) and \(RR_x\) the relative risk for \(x\) grams per day.

The latent period (or interval between 'exposure' to fruit and vegetables and the appropriate decrease in risk of these cancers) is not known. Prospective studies of diet and cancer (from which the estimates of relative risk are mostly drawn) involve follow-up periods (between estimated dietary intake and cancer onset) of several years. For the cohort studies contributing to the meta-analyses of WCRF, 10 studies of lung cancer and 6 of stomach cancer reported the mean duration of follow-up; the simple means were 15.2 and 10.3 years, respectively. There are a few cohort studies on upper GI cancers: the follow-up periods in the EPIC study (González et al., 2006) and Japanese JPHC studies (Yamaji et al., 2008) were 6.5 and 7.7 years, respectively. For the purposes of estimating attributable fraction, we assume a mean latency of 10 years, and thus examine the effects on cancers occurring in 2010 of sub-optimal levels of fruit and vegetable consumption in 2000. Consumption of fruit and vegetables, in grams per week, by age group and sex, is available for 2000–2001 from the National Diet & Nutrition Survey (FSA, 2004; Table 2.1). The mean consumption, by age group, is shown in Table 2. The target consumption of 400 g per day was not achieved at any age, and the young, in particular, had a low consumption of such items.

### Table 1
Estimated risks associated with a decreased consumption of 1 g per day of fruits and non-starchy vegetables

| Cancer type         | Fruit | Vegetables* |
|---------------------|-------|-------------|
| Oral cavity and pharynx | 0.00488 | 0.00416 |
| Oesophagus          | 0.00504 | 0.00266 |
| Stomach             | 0.00234 | 0.00320 |
| Colon–rectum        | 0      | 0           |
| Larynx              | 0.00322 | 0.00370 |
| Lung                | 0.00146 | 0           |

*Non-starchy vegetables.

### Table 2
Mean consumption of fruit and non-starchy vegetables by sex and age group, Great Britain 2000–2001

| Vegetables or fruit | 19–24 | 25–34 | 35–49 | 50–64 | 19–64 |
|--------------------|-------|-------|-------|-------|-------|
| Men                |       |       |       |       |       |
| Vegetables (g per day) | 95    | 122   | 144   | 162   | 137   |
| Fruit (g per day)   | 27    | 61    | 99    | 122   | 87    |
| Women               |       |       |       |       |       |
| Vegetables (g per day) | 89    | 130   | 139   | 143   | 132   |
| Fruit (g per day)   | 54    | 74    | 98    | 151   | 103   |
| Persons             |       |       |       |       |       |
| Vegetables (g per day) | 92    | 126   | 141   | 153   | 135   |
| Fruit (g per day)   | 40    | 68    | 99    | 137   | 95    |

### Table 3
Proportions of the Great Britain population in seven categories of fruit and vegetable consumption in 2000–2001, and estimated deficit in consumption in each category from the recommended 400 g per day

| Consumption categories in 2000–2001 |
|-------------------------------------|
|                                    |
| Sex and age (years)                 |
|                                    |
|                                    |
| Men 19–49                           |
| Proportion of the population        |
| 0.01                                |
| Vegetables (g per day)              |
| 0                                   |
| Deficit from 256 g per day          |
| 256                                 |
| Fruit (g per day)                   |
| 0                                   |
| Deficit from 144 g per day          |
| 144                                 |
| Men 50–64                           |
| Proportion of the population        |
| 0.01                                |
| Vegetables (g per day)              |
| 0                                   |
| Deficit from 228 g per day          |
| 228                                 |
| Fruit (g per day)                   |
| 0                                   |
| Deficit from 172 g per day          |
| 172                                 |
| Women 19–49                         |
| Proportion of the population        |
| 0.01                                |
| Vegetables (g per day)              |
| 0                                   |
| Deficit from 242 g per day          |
| 242                                 |
| Fruit (g per day)                   |
| 0                                   |
| Deficit from 158 g per day          |
| 158                                 |
| Women 50–64                         |
| Proportion of the population        |
| 0.01                                |
| Vegetables (g per day)              |
| 0                                   |
| Deficit from 195 g per day          |
| 195                                 |
| Fruit (g per day)                   |
| 0                                   |
| Deficit from 205 g per day          |
| 205                                 |
The National Diet & Nutrition Survey also provides the distribution of intake of fruit and vegetables in the British population, in terms of the cumulative percentage of individuals (by sex and age group) consuming 0, <1, <2, ..., >5 portions of fruit and vegetables daily (FSA, 2004; Table 3). The populations of each sex were dichotomised into two age groups (<50 and 50–64), and ‘portions’ were converted into grams (of fruit and vegetables), such that the mean daily intake corresponded to the values in Table 2. Table 3 shows the results in terms of the proportions of the population at seven different levels of consumption of fruit and vegetables.

To calculate the deficit in consumption of fruit and vegetables relative to a target of 400 g per day for both, the deficit in each sex and age group (19–49, 50–64) was calculated from Table 2. For example, the deficit in older men (50–64) was, on average, 216 g per day (400 – (162 + 122)). The total deficit is partitioned into deficits of fruit and vegetables, so that the same ratio of vegetables to fruit that was being eaten in 2000–1 is maintained. Thus, the 400 g per day target for consumption in men in the age group of 50–64 years is partitioned in the ratio of 162:122 (Table 2); i.e., 228 g per day vegetables and 172 g per day fruit (Table 3). The deficit of each in the different consumption categories in men and women aged <50 years and in the age group of 50–64 is shown in Table 3.

For each cancer, the relative risk in 2010 in the four age–sex strata is calculated from the deficit in consumption 10 years earlier (2000–2001), with the risk for fruit and vegetables calculated separately according to the following formula:

$$RR = (\exp(R_0 \times G_x))$$

where $R_0$ is the relative risk for a deficit of 1 g per day of fruit or vegetables (Table 1) and $G_x$ is the deficit in consumption (as shown in Table 3) in consumption category $x$.

The benefits of fruit and vegetables are considered to be multiplicative in their effect, so that

$$RR(f \text{ and } v) = RR(f) \times RR(v)$$

Population-attributable fractions were calculated for each of the four sex–age groups in Table 3 according to the following formula:

$$PAF = \frac{(p_1 \times ERR_1) + (p_2 \times ERR_2) + (p_3 \times ERR_3) + (p_4 \times ERR_4)}{1 + (p_1 \times ERR_1) + (p_2 \times ERR_2) + (p_3 \times ERR_3) + (p_4 \times ERR_4)}$$

where $p_i$ is the proportion of population in consumption category $x$ and $ERR_i$ the excess relative risk ($RR(f \text{ and } v) - 1$) in consumption category $x$.

**RESULTS**

Table 4 shows the PAFs and the estimated number of cases ‘caused’ in 2010 by these deficits in consumption of fruit and vegetables 10 years earlier. The cancers for which the greatest proportion of cases may be related to low intake of fruit and vegetables are the oral cavity and pharynx (56%), oesophagus (46%) and larynx (45%). Although only 9% of lung cancer cases may be related to low intake of fruit (there is no excess risk of lung cancer from low intake of vegetables), the actual number of cases (3567) represents almost one-quarter of the total number of cancers attributable to low intake of fruit and vegetables (14,902; Table 5).

Table 5 sums the excess numbers of cases at the five sites, caused by low consumption of fruit and vegetables, and expresses these numbers as a fraction of the total burden of (incident) cancer. The estimate is 6.1% cancers in men and 3.4% in women, or 4.7% of cancers overall.

---

**Table 4** Cancer cases in 2010 at six sites caused by deficient intake of fruit and vegetables in 2000–2001

| Outcome site | At age (years) | At outcome + (10 years) | PAF | Excess attributable cases |
|--------------|---------------|------------------------|-----|--------------------------|
| Men          | 19–49         | 29–59                  | 0.65 | 18174 1233/0.56 1064 | 596/0.49 567 265/0.00 3410 |
| Women        | 19–49         | 29–59                  | 0.64 | 786 503/0.55 332 184/0.47 335/0.41 2791 |
| Total (%)    | 60–64         | 0.52 4352 1616/0.75 5193 | 0.45 4693 3973/0.67 1371 | 18467 1651/0.66 2887 |

**Table 5** Summary of cancer cases in 2010 at five sites caused by deficient intake of fruit and vegetables 10 years earlier

| At outcome + (10 years) | PAF | Excess attributable cases |
|-------------------------|-----|--------------------------|
| Men                     |     |                          |
| 19–49                   |     |                          |
| 29–59                   |     |                          |
| ≥60                     |     |                          |
| Total (%)               | 0.52 | 4352 1616/0.75 5193 |
| Women                   |     |                          |
| 19–49                   |     |                          |
| 29–59                   |     |                          |
| ≥60                     |     |                          |
| Total (%)               | 0.50 | 2359 1265/0.51 762 |

**Abbreviations:** Obs = observed cases; PAF = population-attributable fraction.
main dietary source of many micronutrients and other metabolically active chemicals. The types and quantities of these compounds vary between items, which may explain why most studies measuring cancer risk in relation to overall intake tend to show only a weak association (McCullough and Giovannucci, 2004).

In any case, in this section, we have followed the results of the current consensus reviews by WHO/FAO (2003), IARC (2003) and WCRF (2007) with respect to those cancers that might reasonably be caused, in part, by a deficient intake of these dietary elements. The latter report considered that the evidence for a protective effect of vegetables (and, even more so, fruit) on the risk of colon cancer was ‘limited’, and placed more emphasis on the importance of the protective effects of consumption of foods containing dietary fibre than on vegetables per se. This concurs with more recent reviews of the evidence from epidemiological studies (Hoffman et al., 2007; Huxley et al., 2009), and in this section, therefore, we consider that no cases of colorectal cancer are attributable to sub-optimal consumption of vegetables or fruit.

An estimate of the fraction of cancer in UK attributable to low intake of fruit and vegetables was recently published by the WCRF (2009) (Table 6). There are several reasons for the differences in results from the current estimates. WCRF selected ‘representative’ studies from which to take the relative risks, rather than those from their own meta-analyses. Exposure prevalence was taken from data for the same year as outcome (2002). Finally, the baseline category (optimum consumption) varied by site – ≥160 g vegetables per day for oesophagus and stomach cancer; ≥120 g per day for upper aero-digestive cancers; ≥57.1 g fruit per day for stomach cancer; and ≥160 g fruit per day for lung cancer. Given the estimates by site in Table 6, the overall AF (for all cancers) due to low consumption of vegetables and fruits would be 7.1% – of which almost 60% are lung cancers, because of the large attributable fraction (33%) and high incidence of this cancer.

See acknowledgements on page Si.

Conflict of interest

The authors declare no conflict of interest.

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