EPIDEMIOLOGICAL EVIDENCE ON ENVIRONMENTAL TOBACCO SMOKE AND BREAST CANCER

A REVIEW WITH META-ANALYSES

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EXECUTIVE SUMMARY

Results of 22 studies relating breast cancer in women to ETS exposure in non-smokers have been published. This document presents a comprehensive review of the evidence, with meta-analysis.

The studies varied in design and in the ETS exposure indices used. Based on a single estimate from each study relating to the index of exposure most nearly equivalent to ever smoking by the spouse or partner, random-effects meta-analysis gave an overall estimate of 1.12 (95% CI 1.02-1.24). However, the 22 estimates were significantly ($p<0.001$) heterogeneous, with estimates close to 1.00 based on prospective studies, on North American studies, on larger studies (>500 cases) and on studies taking more confounding variables than average into account, and significantly elevated in case-control studies (1.28, 1.07-1.53), in European studies (1.50, 1.14-1.97), in smaller studies (1.27, 1.03-1.57), and in those studies that had taken fewer confounding variables than average into account (1.23, 1.03-1.45). In those studies providing relevant data, there was no evidence of an association in postmenopausal women, but a clear increase in premenopausal women (1.54, 1.16-2.05).

Evidence of a dose-response relationship was similarly heterogeneous, with significant trends reported in a few studies contrasting with a complete lack of relationship reported in other studies.

There was no evidence of an association at all for childhood ETS exposure, and the increased relative risk estimate was not significant using indices based specifically on exposure from the spouse, in the workplace or from the spouse or other cohabitant. However it was notable that from those six studies that provided estimates relating to total exposure, based on a detailed questionnaire that asked (at least) about at-home exposure in childhood and in adulthood and about workplace exposure, the relative risk estimate was quite high (1.54, 1.17-2.04).

Detailed examination of the evidence suggested that where associations were seen, the elevated risk estimate derived mainly from case-control studies that asked very detailed questions about ETS exposure, and depend heavily on the accuracy of

the reported answers. Expressing estimates relative to a totally unexposed baseline produces estimates that are highly dependent on which subjects happen to get classified in the baseline group and may well be unusually subject to recall bias. Results from large prospective studies involving very detailed ETS exposure indices would aid interpretation, but to date are lacking.

Also relevant to interpretation of the data are weaknesses inherent in a number of studies and the possibilities of publication bias and uncontrolled confounding.

Overall, in view of the inherent implausibility that ETS exposure might cause breast cancer, given the virtually identical risks in smokers and nonsmokers, and the doubts about the reliability of estimates from case-control studies involving extremely detailed questionnaires on ETS exposure, one cannot conclude that ETS exposure has actually been shown to increase the risk of breast cancer in nonsmokers.

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INTRODUCTION

A recent collaborative re-analysis by the Oxford Group [1] of individual data on alcohol, tobacco and breast cancer from 53 epidemiological studies concluded that smoking has little or no independent effect on the risk of developing breast cancer. Paradoxically, in view of this conclusion, a number of epidemiological studies have suggested a possible increase in risk in lifelong non-smokers associated with exposure to environmental tobacco smoke [ETS] exposure [2,3], though this seems to have been contradicted by recent large US prospective studies [4-6] showing little or no relationship.

In view of these findings and the appearance of a number of other recent relevant publications [7-15], this review attempts to assess the available evidence to date. Attention has been restricted to epidemiological studies of breast cancer in which the relationship of mortality or incidence to one or more indices of ETS exposure has been studied in lifelong non-smokers. The need to have results available for lifelong nonsmokers has meant that some studies which might at first have seemed to provide relevant information [16-21] have been excluded from consideration.

When this review was virtually complete, we became aware of an E-publication version of a recent similar review by Johnson [22]. This review also comments briefly on that review.

METHODS

In June 2005, publications describing the results of epidemiological studies relating the risk of breast cancer in non-smoking women to ETS exposure were sought from MEDLINE searches, from the extensive files on smoking and health accumulated by P N Lee Statistics Computing Ltd (PNLSC), and from reference lists of papers retrieved.

From these publications details were extracted of the study location and design and of the potential confounding variables considered. Where available, estimates of the relative risk (RR)*, together with the associated 95% confidence interval (CI), were extracted relating to ETS exposure at home, at work, in adulthood, in childhood and in life. For a given exposure, those RRs which adjusted for the greatest number of potential confounding variables were selected for analysis. Where RRs were only presented by subgroup (e.g. pre- and post-menopausal women), estimates for the total population were combined by fixed-effects meta-analysis [23]. Where adjusted results were given only by level of exposure, RRs and CIs for overall exposure were estimated as described by Fry and Lee [24,25]. For a given exposure, RRs were obtained, where possible, comparing women exposed and unexposed to the exposure of interest. Exceptions to this are noted in the tables. RRs were also extracted by subgroup, where available.

Fixed-effects and random-effects meta-analyses were conducted using standard methods [23]. An order of preference was used for a "principal" meta-analysis. Thus, selection was based firstly on type of exposure (spouse highest preference, then partner, cohabitant, home or work) and secondly on time of exposure (for spouse or partner preferring ever to current, and, for other types of exposures, adulthood to ever in life). This was intended to be the nearest available index equivalent to ever exposure from the spouse. Other endpoints used in meta-analyses are discussed later.

* Note that in this review, the term "relative risk" is taken to include not only direct estimates of the RR from prospective studies, but also indirect estimates (odds ratios) from cross-sectional studies.

RESULTS

The studies

The studies are identified by the first author of the principal publication, with the two studies by Lash and Aschengrau [10,26] identified as Lash I and Lash II. As shown in Table 1, two of the studies were published in the 1980s, five in the 1990s and 15 between the years 2000 and 2005. This reflects a massive upsurge of interest in studying the possibility that ETS might cause breast cancer. The Rookus and Woo studies [27,28] were published only as abstracts.

Of the 22 studies, 11 have been conducted in North America (10 in the USA, one in Canada), six in Asia (three in Japan, two in China, one in Korea) and five in Europe (one each in the UK, Switzerland, Netherlands, Germany and Norway/Sweden).

Eight of the studies were of prospective design, with follow-up varying from six to 16 years. The majority of these studies concerned onset of breast cancer, but the Hirayama and Wartenberg studies [4,29] used breast cancer mortality as the endpoint, based on death certificates. The Woo study [28] was a nested case-control study within a prospective study of incident breast cancer. The remaining thirteen studies were of case-control design, mainly using population controls. However, the Sandler study [30] used friends of cases or controls, which are not necessarily representative of the population, and two used hospital-based controls, the Delfino study [31] using benign breast disease patients, and the Liu study [32] patients without cancer. Most of the case-control studies collected the information directly from the subject herself, but the Lash I and Lash II studies [10,26] used proxy interviews for deceased cases and their matched controls. Results were mainly reported for breast cancer cases as a whole, but some results from the Morabia and Gammon studies [11,33] were reported by the hormone receptor status of the cases, while some results from the Gammon study [11] were also reported separately for *in situ* and invasive cases.

A variety of ETS exposure indices were studied. In the Hirayama and Jee studies [29,34], both conducted in Asia, only exposure from the spouse was studied. An additional 10 studies [6,10,11,13,26,28,30,31,35,36] restricted attention to at-

home exposure. The other 10 studies collected information on more extensive sources of exposure, either individually or totally.

15 of the 22 studies presented results not only for the whole population of non-smokers studied, but also for subgroups of the population. Most commonly (11 studies), this was for subgroups defined by menopausal status, but four studies gave results by age (or age of husband) and five studies gave results by genetic status (NAT1, NAT2, p53 and/or SULT1A1).

Table 2 lists the potential confounding variables adjusted for in analysis. The Rookus and Woo two studies [27,28] published only as abstracts did not make it very clear which variables had been adjusted for. Of the other 20 studies, all had adjusted for age, except for the Hirayama study [29], which adjusted for age of the husband. The Hirayama and Sandler studies [29,30] adjusted for no other variables, but the rest adjusted for between two and 16 variables. Apart from age, there were a number of variables that were adjusted for in at least 10 studies, including age at menarche, age at pregnancy (or birth), parity (or numbers of births), family history of breast cancer, personal history of benign breast disease, alcohol consumption, menopausal status (or age at menopause), and body mass index (or other similar indices of obesity). These are all well known risk factors for breast cancer. Other less commonly considered variables included education (or socio-economic status), hormone use and aspects of diet, considered in respectively eight, seven and five studies.

Relative risk estimates and meta-analyses

Tables 3-6 give RRs (with CIs) for, in turn, ETS exposure from the spouse or at home; other sources of ETS exposure in adulthood; ETS exposure in childhood; and total lifetime ETS exposure. Table 7 gives RRs by subgroups of the data. Table 8 gives the results of various meta-analyses.

The results for indices of ETS exposure at home shown in Table 3 are based on 19 studies. Statistically significantly increased ($p<0.05$) RRs and/or dose-related trends were seen in three studies [26,32,33], but the more recent studies show no evidence at all of an increase.

Eight of these studies presented results specifically for exposure from the spouse (or partner in the Smith study [37]). Combining these estimates (and selecting the result for spouse ever smoked for the Wartenberg study [4]) gives, as shown in Table 8, a fixed-effects meta-analysis estimate of 1.08 (0.97-1.21), which is not statistically significant ($p>0.05$). There is evidence of significant ($p<0.01$) heterogeneity, due mainly to the high RR estimate of 3.1 in the Morabia study [33] and the low RR estimate of 0.58 in the Nishino study [36]. When random-effects meta-analysis is carried out, the RR estimate is increased, to 1.20, but remains non-significant (95% CI 0.96-1.49).

Based on the first RR cited in Table 3 for those studies where multiple estimates are available, the fixed-effects meta-analysis estimate for exposure at home is 1.02 (0.97-1.08) while the random-effects estimate is 1.08 (0.98-1.18). Again, the high estimate from the Morabia study [33] is the largest contributor to the significant ($p<0.01$) heterogeneity.

The results shown in Table 4 for other sources of ETS exposure in adulthood are based on eight studies. Five studies gave RRs for workplace exposure (or not-home exposure), with the Liu and Shrubsole studies [12,32] showing significant RRs or trends. The estimates are significantly ($p<0.05$) heterogeneous, with the low estimate of 0.8 (0.6-1.0) from the Wartenberg study [4] contrasting with estimates above 1.0 from the other studies. No significant overall effect is seen, whether fixed- or random-effects meta-analysis is used (see Table 8).

Table 4 also gives RRs from six studies for either any adult exposure or for home or workplace exposure. Significantly increased RRs are seen in the Johnson and Kropp studies [9,38], and, overall, a marginally significant ($p<0.05$) elevated risk is seen, based on either fixed-effects (1.13, 1.02-1.25) or random-effects (1.19, 1.00-1.42) analysis. Again, the results are significantly ($p<0.05$) heterogeneous.

The results for childhood exposure shown in Table 5 are from nine studies. Most of the RRs are quite close to 1.0 and none are statistically significant, although the Liu study [32] did report a significant positive trend. Based on the first RR cited

in Table 5 for those studies where multiple estimates are available, the nine estimates show no significant heterogeneity and give an overall estimate of 0.99 (0.91-1.08).

Table 6 presents results from six studies for an index of total lifetime exposure, three [9,27,38] based on questions restricted to home and work, and three based on a wider definition [14,33,37]. Significant increases and dose-related trends are seen in the Morabia, Johnson and Kropp studies [9,33,38]. Although there is significant ($p<0.05$) heterogeneity, all the relative risk estimates are above 1, and quite high overall estimates are seen using either fixed-effects (1.44, 1.21-1.72) or random-effects (1.54, 1.17-2.04) meta-analysis.

For some studies, the footnotes of Tables 3, 5 and 6 summarize additional results by time of exposure, by type of case or by product smoked. Generally, there was no evidence of significant variation by any of these factors. The only exception was in Table 3 for the Lash II study [10], where a significant variation in risk according to whether time of first exposure was before or after first pregnancy was due to a reduced RR in the latter group.

Table 7 presents RRs by subgroup. Of the 11 studies that reported findings separately for pre- and postmenopausal women, the studies by Sandler, Woo and Hanaoka [14,28,39] reported RRs that were significantly higher in premenopausal than postmenopausal women, indeed finding no increase at all for postmenopausal women. In the Delfino and Johnson studies [31,38] a similar pattern was seen, but the variation by menopausal status was not significant. The remaining six studies showed no evidence of such variation.

As shown in Table 8, the 10 studies that presented actual RR estimates by menopausal status provided no real indication of an effect of ETS on breast cancer risk in postmenopausal women. ETS exposure was, however, associated with a significant increase in risk in premenopausal women. However, there was marked heterogeneity ($p<0.01$) and the random-effects estimate (1.54, 1.16-2.05) was higher than the fixed-effects estimate (1.21, 1.05-1.40). Similar results were obtained when the ratio, for each study, of the RR for premenopausal women to that for postmenopausal women was meta-analysed.

There was no evidence of any significant variation in RR by genetic status (NAT1, NAT2, p53, SULT1A1), by age or by any other subgroup. The only minor exception was a tendency in the Gammon study [11] for RR to vary by body mass index rather more than expected. However, the variation was not systematic, and may well be due to chance.

Principal meta-analysis

As described in the methods section, a principal meta-analysis was carried out using one estimate from each of the 22 studies, choosing that which was most equivalent to the classic exposure index of "spouse ever smoked". The estimates used included all 19 RRs considered in the meta-analysis of spouse or cohabitant exposure (Table 3), together with the RRs from the Johnson study [38] and the Kropp study [9] from Table 4, and from the Rookus study [27] from Table 6. They are marked with an "m" in the notes column of these three tables.

Overall, these 22 studies give a fixed-effects estimate of 1.05 (0.99-1.11) which is not quite significant. However, there is highly significant ($p<0.001$) heterogeneity, the largest contribution being from the high RRs in the Morabia study [33] and the Kropp study [9]. As a result, the random-effects estimate is somewhat higher (1.12, 1.02-1.24), and is now statistically significant.

In an attempt to study possible sources of heterogeneity, risks were compared by various different factors – study type, continent, study size and degree of adjustment for confounding. As noted below, there was significant variation in the RR estimate for ETS exposure between the levels of all these factors.

Study type : The nine prospective studies provide no evidence of an effect, with no significant heterogeneity, and individual estimates varying from 0.58 to 1.32. In contrast, the 13 case-control studies do show an association, with both fixed-effects estimates (1.16, 1.05-1.28) and random-effects estimates (1.28, 1.07-1.53) statistically significant. The estimates for the case-control studies are significantly heterogeneous ($p<0.01$).

Continent : Though the results from the 11 North American studies are somewhat heterogeneous ($p<0.1$), both the fixed-effects estimate (0.99, 0.93-1.06) and the random-effects estimate (1.02, 0.93-1.13) are close to 1. In contrast, the results from the five European studies, though again somewhat heterogeneous ($p<0.1$), show a marked and significant increase for both estimates: fixed-effects 1.37 (1.17-1.60), random-effects 1.50 (1.14-1.97). The estimates from the six Asian studies are statistically homogeneous, and show a non-significant increase in risk: fixed-effects 1.08 (0.94-1.24), random-effects 1.09 (0.90-1.33). The heterogeneity between continents is very highly significant ($p<0.001$).

Study size : The results from the seven largest studies, involving over 500 cases, show no evidence of heterogeneity and combined risk estimates close to 1. In contrast, the 13 smaller studies show significant ($p<0.001$) heterogeneity and a significant increase, whether fixed-effects estimates (1.18, 1.05-1.33) or random-effects estimates (1.27, 1.03-1.57) are considered.

Adjustment for confounding : Studies were divided, approximately equally, into those that had adjusted for nine or more potential confounding variables other than age and those that had adjusted for eight or less. In both groups, there is significant heterogeneity. In the nine studies that had adjusted for nine or more potential confounding variables, there was no significant evidence of an association of ETS with breast cancer (fixed-effects 0.99, 0.93-1.06, random-effects 1.05, 0.93-1.19) but, in the group that had adjusted for eight or less, there was a significant relationship (fixed-effects 1.20, 1.08-1.35, random-effects 1.23, 1.03-1.45).

DISCUSSION

Based on 22 estimates of the risk of breast cancer associated with ever having a husband who smoked, or the nearest equivalent ETS exposure index available, random-effects meta-analysis gives a marginally significant ($p<0.05$) increased RR estimate of 1.12 (1.02-1.24). In assessing this association in terms of a causal relationship, various issues have to be taken into account, which are discussed in the sections that follow.

Plausibility

Given that smokers have a risk of breast cancer that is similar to that of nonsmokers [1] is it plausible that ETS exposure might have a true effect on the risk? In considering this question, one must realise that the denominators are not the same in the two relative risk calculations, with the risk in smokers compared to that in all nonsmokers, whether ETS exposed or not. To see what effect this has assume that among the nonsmokers a proportion p are unexposed to ETS and have a risk of 1 unit, while a proportion 1-p are exposed and have a risk of E units. The nonsmokers as a whole, therefore, have an average risk of $p+(1-p)E$ units. Let us also suppose that smokers, relative to the totally unexposed group, have a true risk of S units. The observation that the risk is the same in smokers as in all nonsmokers therefore implies that $S = p+(1-p)E$, and hence that the risk from smoking is less than that from ETS exposure, with approximate equality being obtained only if p is small.

There are two main reasons why it seems implausible that ETS exposure might have a greater effect on risk that active smoking. One is that exposure to smoke constituents is in general very much higher from smoking than from ETS. For example, cotinine levels are typically some hundreds of times higher in active smokers [40]. Even though, for some smoke constituents, concentrations in sidestream smoke substantially exceed concentrations in mainstream smoke, nonsmokers are not exposed to neat sidestream, but to smoke that has been considerably diluted and has aged. The second main reason is that smokers are exposed to higher levels of ETS exposure than are nonsmokers, not only because they are more likely to mix with other smokers, but also because they are exposed to ETS from their own cigarettes. To fit the observations one would have to argue that ETS exposure is carcinogenic to the breast, but that smoking is anti-carcinogenic. While

one can speculate that protective anti-oestrogenic effects operate only in smokers, it seems implausible that positive and negative effects of smoking should neatly balance out to end up with smoker/nonsmoker relative risks so close to 1. *A priori* it might seem more plausible that no true effects of smoking or ETS exposure exist, with observed increases in risk associated with ETS in some analyses due to one or more of the biases possible in epidemiological studies.

Consistency

The 22 estimates are highly significantly ($p<0.001$) heterogeneous. Risk estimates are close to 1.00 in prospective studies, in North American studies, in larger studies (>500 cases) and in studies that had taken more confounding variables than average into account. Conversely, risk estimates are significantly elevated in case-control studies (random-effects RR 1.28, 1.07-1.53), in European studies (1.50, 1.14-1.97), in smaller studies (1.27, 1.03-1.57) and in studies that had taken fewer confounding variables than average into account (1.23, 1.03-1.45).

It is also notable that in those 10 studies which provided estimates separately for premenopausal and postmenopausal women, there is no evidence of an association in postmenopausal women but a clear increase in premenopausal women (1.54, 1.16-2.05).

Although there is no evidence of any association for childhood ETS exposure, and the increase is not significant for workplace ETS exposure, there is more evidence of an association for ETS exposure indices involving multiple sources of exposure. Indeed six studies provided estimates relating to total exposure based on a questionnaire that asked (at least) about at-home exposure in childhood and in adulthood and about workplace exposure, and these studies produce a relatively high random-effects estimate of 1.54 (1.17-2.04).

Assessment of ETS exposure

All these variabilities are clearly not independent, and it appears that many arise because of relatively high RR estimates in those case-control studies which asked very detailed lifetime ETS exposure histories [9,27,33,37,38]. Indeed, if these five studies (Smith, Morabia, Johnson, Rookus, Kropp) are omitted from the meta-

analyses in Table 8 (data not shown in detail), virtually all the associations shown there become non-significant, whether fixed-effects or random-effects meta-analysis is used. The only exceptions are the meta-analysis of studies adjusting for few confounders (for which the fixed effects estimate remains marginally significant but the random effects estimate is non-significant) and the evidence of an effect in premenopausal women. For the latter, a random-effects estimate based on eight studies gives a marginally significant estimate of 1.40 (1.04-1.88) with clear evidence of heterogeneity ($p<0.01$) still evident, the fixed-effects estimate being much lower and not significant (1.15, 0.99-1.33).

The question arises as to whether one should draw inferences based on analyses involving single sources of ETS exposure (such as the spouse or the workplace) or on analyses involving overall exposure from multiple sources. The arguments for and against are not straightforward. Asking a subject whether their spouse smoked during their marriage has the advantage of being easy to understand, and quite likely to be answered accurately. Furthermore it is well documented that marriage to a smoker (and working with a smoker) are associated with increased overall ETS exposure, as judged by levels of cotinine in blood, urine or saliva [40]. However, it is in theory possible that studies based on a limited assessment of ETS may lack the power to detect any true effect that studies based on a more detailed assessment would have. This may be particularly true for childhood exposure where comparing subjects who were and were not exposed in childhood includes those with varying amounts of adult ETS exposure in both numerator and denominator.

In some case-control studies very detailed questions have been asked about multiple sources of ETS over the whole of the subject's lifetime, and analyses have been conducted using those with no reported exposure at all as the comparison group. The problem with this approach is that everyone is likely to have had some ETS exposure in their life and the estimates of risk are highly dependent on which subjects happen to get classified in the possibly small unexposed comparison group. If a relatively low level of actual ETS exposure is more likely to be reported by cases, perhaps in an effort to explain their disease, than by controls, such differential recall may cause substantial bias to the estimated effects of ETS. It is notable that of the six studies considered in Table 6 reporting risk estimates relating to a total estimate of

ETS exposure based, at least, on workplace exposure, and on at-home exposure in childhood and in adulthood, it was the case-control studies that showed evidence of an increase, the only prospective study reporting a non-significant RR close to 1.0.

Dose-response relationship

Assessment of the existence of a dose-response relationship is made difficult by the lack of data from a number of studies, and by the heterogeneous nature of the results that are available. Corresponding to the 22 estimates for the principal ETS exposure index, dose-response data were only available for 10 studies, and in the majority of these no trend was evident, with estimates close to unity for all levels of the dose-response metrics considered in the Wartenberg, Egan, Lash II, Gammon and Shrubsole studies [4,5,10-12] and only two studies showing a statistically significant trend. Though Liu [32] showed a response that clearly increased within the exposed groups, the Morabia study [33] did not, the relative risk estimates being similar, 3.1 and 3.2, for 1-50 and >50 hours/day-years ETS exposure from the spouse, the trend being significant because the risk in the exposed group as a whole was elevated. It is clear that a dose-response relationship has not been demonstrated for this exposure index.

There seems rather more evidence of a dose-response for total exposure (see Table 6), with significant positive trends seen in the Morabia, Johnson and Kropp studies [9,33,38].

Overall, it is not apparent that consideration of dose-response data adds to the case against ETS exposure as a possible cause of breast cancer.

We now consider potential sources of bias other than recall bias:

Misclassification of the subject's smoking status

Misclassification of the subject's smoking status may be a relevant biasing factor in studies of ETS and lung cancer [41], as lung cancer risk is very much higher in smokers than nonsmokers. Here it is doubtful whether breast cancer risk is increased by smoking at all [1] and, even if it is, the inclusion, in the self-reported

nonsmokers, of a few true smokers with a slightly increased risk of breast cancer will have little or no biasing effect.

Confounding

Although, as shown in Table 2, the majority of studies have taken into account quite an extensive list of potential confounding variables, not all did so. An attempt was therefore made to investigate the role of confounding by comparing RR estimates for the principal index of ETS exposure in studies which had adjusted for an above average and below average number of variables. This showed no evidence of an association in studies which adjusted for 9 variables or more, but a significant increase in studies which adjusted for 8 variables or less. Although, at first glance, this may suggest that the overall association may have arisen because of limited attention to confounding in some studies, this inference is not straightforward. The studies which adjusted for 9 variables or more included all the three large prospective studies (Wartenberg, Egan and Reynolds [4-6]) which found no association of ETS exposure with breast cancer risk, and which together contributed about 75% of the total weight (inverse variance) of the meta-analysis.

Another approach is to look at the effect of adjustment in specific studies, by comparing RR estimates adjusted only for age with those adjusted for age and additional potential confounders. In fact, only the Smith, Wartenberg, Egan and Hanaoka studies [4,5,14,37] presented both sets of results, and these found the two sets of estimates to be very similar.

Overall, the evidence does not demonstrate any important role of uncontrolled confounding.

Publication bias

It is notable that though results from American Cancer Society Cancer Prevention Study II have been published by Wartenberg *et al* [4] results from the earlier large Cancer Prevention Study I have not been. Results have been reported for some other diseases [42,43] and the data could have contributed to the overall literature. Whether there are other large studies that could have provided data, but have not done so, is unclear. The tendency for authors to be more likely to submit,

and editors more likely to accept, papers showing an association is well documented [44].

Study weaknesses

There are a number of weaknesses that are common to many or a number of the studies:

(i) small number of cases, with some of the analyses in Tables 3-6 being based on less than 100 cases, with consequent variability of the estimate;

(ii) prospective studies of some years duration, determining ETS exposure and other risk factors only at baseline, so not allowing for possible changes in exposure. As shown in Table 1, there were six prospective studies involving nine years of follow-up or more, and in none of them were repeat interviews carried out;

(iii) general reliance on ETS exposure reported by the subject (or, in the Lash I and Lash II studies [10,26], by the next-of-kin for some subjects) with no confirmation by cotinine or by other sources of information; and

(iv) failure in many studies to restrict attention to married subjects when analysing spousal exposure or to control for household size when analysing household exposure.

Some other issues related to specific studies also deserve comment:

(i) in the Sandler study [30] friends of cases were used as controls, which seem unlikely to be representative. Also, the proportion of subjects responding by mailed questionnaire and telephone interview varied markedly between cases and controls;

(ii) in the Hirayama study [29] adjustment was for age of the husband, not age of the subject, and mortality tracing was incomplete;

(iii) the Jee study [34] involved only a 35% participation rate of subjects, increasing the likelihood of nonrepresentativeness;

(iv) in the Johnson study [38] non-response rates were very high due to use of mailed questionnaires;

(v) in the Liu study [32] the adjusted analyses reported made no logical sense (see footnote to Table 2), so only unadjusted risks could be used;

(vi) the Rookus and Woo studies [27,28] were only reported as abstracts, so full details were not available to assess study quality;

(vii) in the two Lash studies [10,26] the rate of proxy interviews was high and differed between cases and controls; and

(viii) in the Kropp study [9] the cases were identified in 1992-1995 but the smoking histories were not obtained until 1999-2000, with the interview rate low.

Risk by time of menopause

Of the 10 studies that allowed comparison of the risks associated with ETS exposure in pre- and post-menopausal women, seven were case-control studies, two were prospective studies and one was a case-control study nested in a prospective study. In the case-control studies menopausal status was as at time of interview, following the diagnosis of the cases, whilst in the prospective studies it was at the time of the baseline interview, before follow-up for cancer. The abstract [28] does not make the position clear for the nested, Woo, study. Given the length of follow-up in the prospective studies, from 1995 to 2000 in the Reynolds study [6] and from 1990 to 1999 in the Hanaoka study [14], it is likely that some of the women would have reached the menopause between interview and breast cancer diagnosis, so that the results from the two types of study are not completely comparable.

It should also be noted that many of the women who were postmenopausal at the time of cancer onset would have been exposed premenopausally to ETS. Given the latent period of cancer, it seems difficult to explain why, if there indeed is a true effect premenopausally, there would not be some corresponding effect postmenopausally. It remains unclear why (see Table 7) some studies, but not others, should report an increased risk of breast cancer in premenopausal but not postmenopausal women, and how, if there is indeed a true effect, this relates to time of exposure and time of onset. Any proposed relationship needs to fit in with the observed lack of association of breast cancer with ETS exposure in childhood.

The Johnson Review

The recent review by Johnson [22] concerns a very similar set of data to that considered in this review. There are some differences. He omits the Rookus and Woo studies reported only as abstracts [27,28], he omits giving any results from the

study with apparently unreliable adjusted estimates [32] and includes results from a study by Zhao *et al* [19] where the report in the literature does not present results specifically for lifelong nonsmokers. He also uses somewhat different relative risks in his principal meta-analyses, not concentrating on the nearest equivalent to ever exposure from the spouse. Some other inappropriate estimates may also have been used. For the Millikan study, Johnson uses an estimate from one source [35] when there is a later estimate from another source [8] that is based on considerably more cases. For the Smith study [37] he apparently combines relative risk estimates from 1-200 and 200+ cigarette-years exposure as if they are independent, when they are not, being expressed relative to the same unexposed group.

However the broad findings from Johnson's meta-analyses [22] are very similar to those reached here. In particular, both sets of meta-analysis find an increased risk in case-control but not prospective studies, and in pre-menopausal but not post-menopausal women, and evidence of an increase that is concentrated in those studies which collect detailed exposure data, particularly when risks are expressed relating to total exposure versus complete nonexposure.

Although Johnson [22] appropriately points to the need for "cohort studies with thorough positive smoking assessment," he takes the view that recall bias is probably unlikely to explain the associations observed in the case-control studies with very detailed assessment of ETS. One reason for his belief is that two of the studies with detailed exposure assessment [33,38] assessed recall bias and did not find any clear evidence of its existence.

In fact, neither study provided particularly convincing evidence of a lack of important recall bias. For the Morabia study [33] the evidence concerned results from questions asking cases and controls whether or not they were worried about passive smoking, the proportion reporting that they were worried being only slightly, and nonsignificantly, greater in nonsmoking cases (55%) than in nonsmoking controls (50%). Though nonsignificant, the calculated odds ratio of 1.20 (95% CI 0.81-1.76) does not exclude the possibility that cases were actually substantially more likely to be worried. Furthermore, it could also well be that, regardless of worry, cases were

readier to give full details of their ETS exposure as the study may have been more important to them than to the controls.

For the Johnson study [38] the evidence relating to potential recall bias derived from their observation that "when lung cancer risk was assessed using the same target control group, observed lung cancer risks associated with passive smoking were consistent with those in the lung cancer - passive smoking literature." But the lung cancer relative risk, of 1.2, has a very large variability with a 95% CI of 0.7-2.1, and furthermore relates to an exposure index "6 or more years of adult residential exposure to passive smoking" that did not involve all the recorded sources of ETS exposure.

Generally, the review by Johnson [22] does not provide convincing evidence of a true relationship of ETS exposure to breast cancer risk.

SUMMARY AND CONCLUSIONS

Results of 22 studies relating breast cancer in women to ETS exposure in non-smokers have been published. This document presents a comprehensive review of the evidence, with meta-analysis.

The studies varied in design and in the ETS exposure indices used. Based on a single estimate from each study relating to the index of exposure most nearly equivalent to ever smoking by the spouse or partner, random-effects meta-analysis gave an overall estimate of 1.12 (95% CI 1.02-1.24). However, the 22 estimates were significantly ($p<0.001$) heterogeneous, with estimates close to 1.00 based on prospective studies, on North American studies, on larger studies (>500 cases) and on studies taking more confounding variables than average into account, and significantly elevated in case-control studies (1.28, 1.07-1.53), in European studies (1.50, 1.14-1.97), in smaller studies (1.27, 1.03-1.57), and in those studies that had taken fewer confounding variables than average into account (1.23, 1.03-1.45). In those studies providing relevant data, there was no evidence of an association in postmenopausal women, but a clear increase in premenopausal women (1.54, 1.16-2.05).

Evidence of a dose-response relationship was similarly heterogeneous, with significant trends reported in a few studies contrasting with a complete lack of relationship reported in other studies.

There was no evidence of an association at all for childhood ETS exposure, and the increased relative risk estimate was not significant using indices based specifically on exposure from the spouse, in the workplace or from the spouse or other cohabitant. However it was notable that from those six studies that provided estimates relating to total exposure, based on a detailed questionnaire that asked (at least) about at-home exposure in childhood and in adulthood and about workplace exposure, the relative risk estimate was quite high (1.54, 1.17-2.04).

Detailed examination of the evidence suggested that where associations were seen, the elevated risk estimate derived mainly from case-control studies that asked very detailed questions about ETS exposure, and depend heavily on the accuracy of

the reported answers. Expressing estimates relative to a totally unexposed baseline produces estimates that are highly dependent on which subjects happen to get classified in the baseline group and may well be unusually subject to recall bias. Results from large prospective studies involving very detailed ETS exposure indices would aid interpretation, but to date are lacking.

Also relevant to interpretation of the data are weaknesses inherent in a number of studies and the possibilities of publication bias and uncontrolled confounding.

Overall, in view of the inherent implausibility that ETS exposure might cause breast cancer, given the virtually identical risks in smokers and nonsmokers, and the doubts about the reliability of estimates from case-control studies involving extremely detailed questionnaires on ETS exposure, one cannot conclude that ETS exposure has actually been shown to increase the risk of breast cancer in nonsmokers.

TABLE 1 – Studies providing data on ETS and breast cancer

Study author [ref][1]	Year[2]	Location	Design[3]	ETS sources studied[4]	Subgroup analyses[5]
Sandler [30,39,45]	1985	USA, N Carolina	CC-F	Sp, Ma, Pa	Age, menopause
Hirayama [29,39,45]	1987	Japan, 6 prefectures	P(16)	Sp	Age of husband
Smith [37]	1994	UK, 11 regions	CC-P	Sp, Oc, Wk, Oa, Ch	-
Morabia [33,46,47]	1996	Switzerland, Geneva	CC-P	Sp, Wk, Oa[6]	Menopause, NAT2 acetylation genotype
Millikan [8,35]	1998	USA, N Carolina	CC-P	Co	Menopause, p53 expression NAT1 and NAT2 acetylation genotypes,
Jee [34]	1999	Korea, nationwide	P(6)	Sp	-
Lash I [26]	1999	USA, Massachusetts	CC-P	Co	-
Delfino [31]	2000	USA, California	CC-B	Co	Menopause, NAT2 acetylation genotype
Johnson [38]	2000	Canada, 8 provinces	CC-P	Co, Wk, Ch	Menopause
Liu [32]	2000	China, Chongqing	CC-H	Co, Wk, Ch	-
Rookus [27]	2000	Netherlands, Amsterdam	CC-P	Co, Wk, Ch	p53 expression
Wartenberg [4]	2000	USA, 50 states[7]	P(12)	Sp, Oc, Wk, Oa	Age, age at marriage
Woo [28]	2000	USA, Maryland	NCC	Co	Menopause
Nishino [36]	2001	Japan, Miyagi	P(9)	Sp, Oc	-
Egan [5]	2002	USA, Nationwide	P(15)	Co, Wk, Ma, Pa	Menopause
Kropp [7,9,15]	2002	Germany, 2 regions	CC-P	Co, Wk, Ch	NAT2 acetylation genotype, SULT1A1 genotype
Lash II [10]	2002	USA, Massachusetts	CC-P	Co	-
Gammon [11]	2004	USA, New York	CC-P	Sp, Oc	Age, menopause, HRT use, body mass index, alcohol, use of oral contraceptives, family history of breast cancer
Reynolds [6]	2004	USA, California	P(6)	Co, Ch	Menopause
Shrubsole [12]	2004	China, Shanghai	CC-P	Sp, Wk	Menopause, most recent job
Gram [13]	2005	Norway and Sweden	P(10)	Co	-
Hanaoka [14]	2005	Japan, 14 districts	P(10)	Co, Ob	Menopause

[1] Studies are identified by the first author of the principal publication

[2] Year of first publication

[3] Design P(n) prospective study with n years of follow-up
CC case-control study; controls indicated by
-B benign breast disease -F friends of cases -H hospital patients without cancer -P population sample
NCC case-control study nested within a prospective study

[4] ETS sources asked about (though results are not necessarily available for all of these)

Ch	childhood (separately)	Oc	other cohabitants (not spouse)
Co	cohabitant	Pa	father (in childhood)
Ma	mother (in childhood)	Sp	spouse (or partner)
Oa	other exposure in adulthood (not home or work)	Wk	workplace
Ob	other exposure in adulthood (not home)		

[5] Subgroup analyses Results (for at least some exposure indices) are reported that relate ETS to breast cancer separately by level of variables listed

[6] Questions were asked about exposures from age 10

[7] Also District of Columbia and Puerto Rico

TABLE 2 – Potential confounding variables adjusted for in results cited in Tables 3-6

Study author [ref][1]	Year[2]	Potential confounding variables adjusted for
Sandler [30,39,45]	1985	Age (only in spousal analyses)
Hirayama [29,39,45]	1987	Age of husband
Smith [37]	1994	Age, region, age at menarche, nulliparity, age at first full-term pregnancy, breast feeding, oral contraceptive use, family history of breast cancer, biopsy for benign breast disease, alcohol
Morabia [33,46,47]	1996	Age, education, body mass index, age at menarche, age at first live birth, oral contraception, family history of breast cancer, history of breast biopsy in all analyses. Also saturated fat, alcohol in first relative risk cited in Tables 3 and 6
Millikan [8,35]	1998	Age, race, sampling fraction, p53 expression
Jee [34]	1999	Age, socioeconomic status, residency, husband's age, husband's vegetable consumption, husband's occupation
Lash I [26]	1999	Age, body mass index, parity, history of radiation therapy, family history of breast cancer, history of breast cancer, history of benign breast disease in all analyses. Also alcohol in first relative risk cited in Table 3, and duration of passive smoking in relative risk cited in Table 5
Delfino [31]	2000	Age, menopausal status, family history of breast cancer
Johnson [38]	2000	Age, province, education, body mass index, alcohol, physical activity, age at menarche, age at end of first pregnancy, number of live births, months of breastfeeding, height, menopausal status
Liu [32]	2000	Age at diagnosis, date of diagnosis, marital status, age at menarche, low body weight in childhood, overweight in adulthood, low family economic situation in youth, history of hospitalised diseases, history of benign breast disease, history of life-stress[3]
Rookus [27]	2000	Lifetime physical activity, other (unspecified) confounders
Wartenberg [4]	2000	Age, race, education, family history of breast cancer, age at first live birth, age at menarche, age at menopause, number of spontaneous abortions, oral contraceptive use, oestrogen replacement therapy use, body mass index, history of breast cysts, alcohol, dietary fat, dietary vegetable, occupation of woman, occupation of spouse
Woo [28]	2000	Menopausal status and possibly other confounders
Nishino [36]	2001	Age, study area, alcohol, green and yellow vegetable intake, fruit intake, age at first birth, number of live births, age at menarche, body mass index
Egan [5]	2002	Age, age at menarche, age at first birth, parity, history of benign breast disease, family history of breast cancer, menopausal status, age at menopause, weight at 18 years, adult weight change, adult height, alcohol, carotenoid intake, menopausal hormone use

TABLE 2 – Potential confounding variables adjusted for in results cited in Tables 3-6 (continued)

Study author [ref][1]	Year[2]	Potential confounding variables adjusted for
Kropp [7,9,15]	2002	Age, alcohol, breastfeeding, education, family history of breast cancer, menopausal status, body mass index
Lash II [10]	2002	Age, vital status, history of radiation therapy, body mass index, family history of breast cancer, history of breast cancer, history of benign breast disease, alcohol, parity, age at first birth
Gammon [11]	2004	Age, history of benign breast disease, body mass index at age 20, family history of breast cancer, fertility problems, number of pregnancies, menopausal status, weight in year before reference date
Reynolds [6]	2004	Age, race, family history of breast cancer, age at menarche, parity, age at first pregnancy, physical activity, alcohol, body mass index, menopausal status, body mass index and menopausal status interaction, hormone therapy use
Shrubsole [12]	2004	Age, education, family history of breast cancer, history of fibroadenoma, age at menarche, parity, age at first birth, menopausal status, age at menopause, physical activity, waist-to-hip ratio
Gram [13]	2005	Age, age at menarche, age at first birth, number of children, menopausal status, family history of breast cancer, hormonal contraceptive use, alcohol, body mass index
Hanaoka [14]	2005	Age, public health centre, employment, education, body mass index, family history of breast cancer, history of benign breast disease, age at menarche, number of births, menopausal status, hormone use, alcohol

[1] Studies are identified by the first author of the principal publication

[2] Year of first publication

[3] The first three variables were matching variables. Results of conditional logistic regression analyses adjusting for all the variables were reported, but only in models which simultaneously considered ETS exposure from three different sources, making the findings not logically comparable to those presented elsewhere. Furthermore, the results are expressed only as an odds ratio per unit of a passive smoking index, and give totally implausible results – for example someone having heavy exposure in adulthood from 3 smokers would have an index value of 9 and an estimated increase in risk by a factor of $4.07^9 = 306443$! Because of this only unadjusted results and those adjusted only for matching variables are included in Tables 3, 4 and 5

TABLE 3 - Relative risk of breast cancer in lifelong nonsmoking women according to ETS exposure from spouse or at home

Study			Source of exposure	Number of breast	Relative risk	Dose	
Author [ref][1]	Location	Type[2]	(timing)[3]	cancers[4]	(95% CI)	response[5]	Notes[6]
Sandler [45]	USA	CC	Spouse (ever)	32	1.62 (0.76-3.44)	-	am
Hirayama [45]	Japan	P	Spouse (ever)	115	1.32 (0.83-2.09)	No	c(1)m
Smith [37]	UK	CC	Partner (adulthood)	94	1.58 (0.81-3.10)	-	ac(9)m
			Other cohabitant (adulthood)	94	1.36 (0.67-2.77)	No	ac(9)e
Morabia [33]	Switzerland	CC	Spouse (ever)[7]	90	3.1 (1.6-6.1)	d1	ac(9)m
Millikan [8]	USA	CC	Cohabitant (ever)	352	0.80 (0.55-1.16)	-	ac(3)em
Jee [34]	Korea	P	Spouse (ever)	138	1.27 (0.91-1.77)	-	ac(5)em
Lash I [26]	USA	CC	Cohabitant (ever)	120	2.0 (1.1-3.7)[8]	No	ac(7)m
Delfino [31]	USA	CC	Cohabitant (ever)[9]	64	1.50 (0.79-2.87)	-	ac(2)m
Liu [32]	China	CC	Cohabitant (adulthood)	186	1.49 (0.96-2.30)	d2	ac(2)em
Wartenberg [4][10]	USA	P	Spouse (ever)	669	1.00 (0.84-1.19)	No	ac(16)em
			Spouse (current)	439	1.0 (0.8-1.2)	-	ac(16)
			Spouse (former)	503	1.0 (0.8-1.2)	-	ac(16)
			Cohabitant (current)	669	1.1 (0.9-1.3)	-	ac(16)
Woo [28]	USA	NCC	Cohabitant (current)	(706)	1.03 (0.81-1.31)	-	c(1?)em
Nishino [36]	Japan	P	Spouse (current)	67	0.58 (0.32-1.10)	-	ac(8)m
			Other cohabitant (current)	67	0.81 (0.44-1.50)	-	ac(8)
Egan [5]	USA	P	Cohabitant (adulthood)[11]	1221	0.94 (0.83-1.06)	No	ac(13)em
Lash II [10]	USA	CC	Cohabitant (ever)	305	0.85 (0.63-1.1)[12]	No	ac(9)m
Gammon [11]	USA	CC	Cohabitant (ever)[13]	598	1.04 (0.81-1.35)[14]	No	ac(7)m
Reynolds [6]	USA	P	Cohabitant (adulthood)	1150	0.97 (0.87-1.10)	-	ac(11)em
			Cohabitant (ever)	1164	0.94 (0.82-1.07)	-	ac(11)
Shrubsole [12]	China	CC	Spouse (ever)	813	1.0 (0.8-1.2)	No	ac(10)m
Gram [13]	Norway, Sweden	P	Cohabitant (ever)	(1130)	1.21 (0.98-1.50)	-	ac(8)m
Hanaoka [14]	Japan	P	Cohabitant (ever)[15]	154	1.0 (0.7-1.4)	-	ac(11)m

[1] Studies are identified by the first author of the principal publication

[2] Study type P = prospective C = case-control NCC = nested case control

[3] Reference group is all lifelong nonsmokers unexposed to the given source, except where indicated by a reference to other notes

[4] Number of breast cancers in lifelong nonsmokers in analysis reported; where this is not known total number of cases in ever smokers is given in brackets

[5] Dose response: "-" indicates dose response not studied, "No" indicates dose-response studied but no significant trend seen, "d1", "d2" indicates dose-response studied, significant trend, with more detailed data as follows:
d1 relative risks are 1.0, 3.1, 3.2 for 0, 1-50, >50 hours/day-years ETS exposure from spouse (trend $p<0.05$)
d2 relative risks are 1.00, 0.47, 1.64, 2.14, 3.09 for 0, light, medium, heavy, very heavy exposure from cohabitants (trend $p<0.01$)
No significant trend for number of smokers at home.

[6] Notes:
- a adjusted for age of subject
- c adjusted for other confounding variables (see Table 2) – number of variables adjusted for is shown in brackets
- e estimated from data reported
- m included in principal meta-analyses
- u unadjusted for any confounding variable

TABLE 3 - Relative risk of breast cancer in lifelong nonsmoking women according to ETS exposure from spouse or at home (continued)

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[7] Reference group is less than 1 hour/day ETS exposure from any source for 12 consecutive months during life
[8] Relative risks are 4.5, 3.8 and 2.4 for, respectively, first exposure <12, 12-20 and 21+ years (heterogeneity not significant)
[9] Cohabitant(s) smoked in their home usually or some of the time
[10] Relative risks are also shown by type of product smoked by spouse (cigarette only, cigar/pipe only, mixed) which respectively are 1.0, 0.8, 1.1 for spouse current smoker and 0.9, 1.3, 1.2 for spouse former smoker – all non significant
[11] Reference group is lived with smoker as an adult for less than 5 years
[12] Relative risks are 0.99, 0.84 and 0.79 for, respectively, first exposure <12, 12-20 and 21+ years (heterogeneity not significant), and are 0.94 for first exposed before first pregnancy and 0.55 for first exposed after first pregnancy (heterogeneity significant at $p<0.05$)
[13] Results are reported for spouse (ever) but have not been included as they appear to be based on ever smokers as well as never smokers
[14] Relative risks are 0.92 for *in situ* cases and 1.07 for invasive cases (heterogeneity not significant) and are 1.15, 0.80, 1.17 and 1.05 for, respectively, ER^+PR^+, ER^+PR^-, ER^-PR^+ and ER^-PR^- cases (heterogeneity not significant)
[15] Reference group is never exposed at home during life and not exposed daily outside the home at baseline

TABLE 4 - Relative risk of breast cancer in lifelong nonsmoking women according to other sources of ETS exposure in adulthood

Study			Source of exposure (timing)[3]	Number of breast cancers[4]	Relative risk (95% CI)	Dose response[5]	Notes[6]
Author [ref][1]	Location	Type[2]					
Smith [37]	UK	CC	Workplace (NOS)	94	1.49 (0.76-2.92)	No	ac(9)e
			Any (NOS)	94	2.52 (0.87-7.31)	No	ac(9)e
Johnson [38]	Canada	CC	Home or workplace (NOS)	606	1.47 (1.06-2.04)	-	ac(11)em
Liu [32]	China	CC	Workplace (NOS)	186	1.54 (1.02-2.32)	d1	ue
Wartenberg [4]	USA	P	Workplace (current)	669	0.8 (0.6-1.0)	-	ac(16)
			Places other than home or workplace (current)	669	0.9 (0.7-1.2)	-	ac(16)
			Any (current)	669	1.0 (0.8-1.2)	No	ac(16)e
Egan [5]	USA	P	Home or workplace (current)	1158	1.09 (0.93-1.28)	No	ac(13)e
Kropp [9]	Germany	CC	Home or workplace (NOS)	197	1.69 (1.16-2.45)	No	ac(6)em
Shrubsole [12]	China	CC	Workplace (last 5 years)[7]	864	1.1 (0.9-1.4)	d2	ac(10)
			Home (ever) or workplace (last 5 years)[7]	864	1.01 (0.79-1.28)	-	ac(10)e
Hanaoka [14]	Japan	P	Outside home, daily (current)[8]	77	1.3 (0.9-1.9)	.	ac(11)

[1] Studies are identified by the first author of the principal publication

[2] Study type P = prospective C = case-control

[3] Reference group is all lifelong nonsmokers unexposed to the given source, except where indicated by a reference to other notes. NOS implies ever in adulthood

[4] Number of breast cancers in lifelong nonsmokers in analysis reported

[5] Dose response: "-" indicates dose response not studied, "No" indicates dose-response studied but no significant trend seen, "d1", "d2" etc indicates dose-response studied, significant trend, with more detailed data as follows:
d1 relative risks are 1.0, 1.56, 0.77, 2.94 for 0, 1-4, 5-9, 10+ smokers at work (trend $p<0.05$)
d2 relative risks are 1.0, 0.9, 1.1, 1.1, 1.6 for 0, 1-59, 60-179, 180-299, 300+ minutes of exposure per day (trend $p=0.02$)

[6] Notes:
- a adjusted for age of subject
- c adjusted for other confounding variables (see Table 2) – number adjusted for shown in brackets
- e estimated from data reported
- m included in principal meta-analysis
- u unadjusted

[7] Analysis restricted to women who had worked during the five years prior to interview

[8] Reference group is never exposed at home during life and not exposed daily outside the home at baseline

TABLE 5 – Relative risk of breast cancer in lifelong nonsmoking women according to ETS exposure in childhood

Study			Source of exposure[3]	Number of breast cancers[4]	Relative risk (95% CI)	Dose response[5]	Notes[6]
Author [ref][1]	Location	Type[2]					
Sandler [30]	USA	CC	Mother	29	0.92 (0.26-3.34)	-	ue
			Father	28	0.91 (0.41-2.04)	-	ue
Smith [37]	UK	CC	Any	94	1.19 (0.55-2.55)	No	ac(9)e
Lash I [26]	USA	CC	At home	99	2.40 (0.78-7.40)[7]	-	ac(8)e
Johnson [38]	Canada	CC	At home	606	1.24 (0.93-1.64)	-	ac(11)e
Liu [32]	China	CC	At home	186	1.16 (0.73-1.84)[8]	d1	ac(2)e
Egan [5]	USA	P	Mother	1222	0.88 (0.74-1.04)	-	ac(13)e
			Father	1222	1.08 (0.96-1.21)	-	ac(13)e
Kropp [9]	Germany	CC	At home	197	1.09 (0.77-1.55)	No	ac(6)e
Lash II [10]	USA	CC	At home	224	1.12 (0.82-1.54)	-	ac(9)e
Reynolds [6]	USA	P	At home	1150	0.95 (0.84-1.07)	-	ac(11)e

[1] Studies are identified by the first author of the principal publication
[2] Study type P = prospective C = case-control
[3] Reference group is all lifelong nonsmokers unexposed to the given source
[4] Number of breast cancers in lifelong nonsmokers in analysis reported
[5] Dose response: "-" indicates dose response not studied, "No" indicates dose-response studied but no significant trend seen, "d1", "d2" etc indicates dose-response studied, significant trend, with more detailed data as follows:
d1 relative risks of 1.00, 1.01, 2.50, 8.98 for 0, 1, 2, 3+ smokers at home (trend $p<0.05$), and 1.00, 0.69, 1.31, 1.64, 1.74 for 0, light, medium, heavy, very heavy exposure at home (trend $p<0.05$)
[6] Notes:
- a adjusted for age of subject
- c adjusted for other confounding variables (see Table 2) – number adjusted for shown in brackets
- e estimated from data reported
- u unadjusted

[7] For exposure at age <12 years
[8] For exposure at age 1-9 years. For exposure at age 10-16 relative risk (95% CI) is 1.06 (0.67-1.68) with no significant dose-response

TABLE 6 – Relative risk of breast cancer in lifelong nonsmoking women according to total lifetime ETS exposure

Study							
Author [ref][1]	Location	Type[2]	Source of exposure[3]	Number of breast cancers[4]	Relative risk (95% CI)	Dose response[5]	Notes[6]
Smith [37]	UK	CC	All	94	2.58 (0.96-6.94)	No	ac(9)e
Morabia [33]	Switzerland	CC	All[7]	126	3.2 (1.7-5.9)[8]	d1	ac(9)
Johnson [38]	Canada	CC	Home or work	606	1.49 (1.02-2.18)	d2	ac(11)e
Rookus [27]	Netherlands	CC	Home or work[9]	918	1.2 (0.8-1.7)[10]	-	c(?)m
Kropp [9]	Germany	CC	Home or work	197	1.59 (1.06-2.39)[11]	d3	ac(6)
Hanaoka [14]	Japan	P	All	162	1.1 (0.8-1.6)	-	ac(11)

[1] Studies are identified by the first author of the principal publication
[2] Study type P = prospective C = case-control
[3] Reference group is all lifelong nonsmokers unexposed to the given source, except where indicated by a reference to other notes
[4] Number of breast cancers in lifelong nonsmokers in analysis reported
[5] Dose response: "-" indicates dose response not studied, "No" indicates dose-response studied but no significant trend seen, "d1", "d2" etc indicates dose-response studied, significant trend, with more detailed data as follows:
d1 relative risks are 1.0, 3.1, 3.2 for 0, 1-50, >50 hours/day-years ETS exposure ever (trend $p<0.05$)
d2 relative risks are 1.0, 1.2, 1.8, 2.0, 3.3, 2.9 for 0, 1-6, 7-16, 17-21, 22-35, 36+ combined years exposure at home and at work (trend $p<0.001$) – data for premenopausal breast cancer; no trend seen for postmenopausal breast cancer
d3 relative risks are 1.00, 1.42, 1.83 for 0, 1-50, 51+ hours/day-years exposure in lifetime (trend $p=0.009$)
[6] Notes:
a adjusted for age of subject
c adjusted for other confounding variables (see Table 2) – number adjusted for shown in brackets
e estimated from data reported
m included in principal meta-analysis
[7] Exposed for at least 1 hour/day ETS exposure from any source for at least 12 consecutive months during life
[8] Relative risks are 2.4 for first exposed before pregnancy and 2.1 for first exposed after first pregnancy (heterogeneity not significant), and are 3.8 for oestrogen receptor negative and 1.8 for oestrogen receptor positive (heterogeneity not significant)
[9] Exposed daily to the smoke of home-smokers or colleagues during at least 20 years or if someone smoked daily in their bedroom during more than one year
[10] Relative risk was noted to be no greater for first exposure before first pregnancy
[11] Relative risks are 1.42 for first exposed before pregnancy and 2.13 for first exposed after first pregnancy (heterogeneity not significant), and are 1.55 for exposure not in previous year and 1.67 for current exposure (heterogeneity not significant)

TABLE 7 - Relative risk of breast cancer in lifelong nonsmoking women according to ETS exposure; subgroup analyses

Study author [ref][1]	Exposure index (timing)[2]	Subgroup	Relative risk (95% CI)	Heterogeneity[3]	Notes[4]
Sandler [39]	Spouse (ever)	Age - <40	4.42 (0.76-25.8)		ue
		40-49	2.85 (0.73-11.1)		
		50+	0.67 (0.20-2.22)	3.98 (2), NS	
		Premenopausal	7.11 (1.35-37.5)		ue
		Postmenopausal	0.89 (0.36-2.22)	4.62 (1), p<0.05	
Hirayama [39]	Spouse (ever)	Husband's age - 40-49	1.45 (0.50-4.17)		ue
		50-59	1.64 (0.77-3.50)		
		60-69	1.02 (0.47-2.21)		
		70-79	0.88 (0.15-5.24)	0.96 (3), NS	
Morabia [46]	All (ever)[5]	Premenopausal	2.21 (1.03-4.75)		ae
		Postmenopausal	2.04 (1.19-3.48)	0.03 (1), NS	
Morabia [47]	All (ever)[5]	NAT2 slow acetylator	1.9 (0.7-4.6)		ac_1
		NAT2 fast acetylator	5.9 (2.0-17.4)	2.40 (1), NS	
Millikan [35]	Cohabitant (ever)	Premenopausal	1.5 (0.8-2.8)		ac_2
		Postmenopausal	1.2 (0.7-2.2)	0.27(1), NS	
		NAT1 * 10	1.38 (0.78-2.44)		ac_3e
		NAT1 – non * 10	1.30 (0.66-2.56)	0.02(1), NS	
		NAT2 slow acetylator	1.46 (0.76-2.80)		ac_3e
		NAT2 fast acetylator	1.19 (0.66-2.16)	0.21(1), NS	
Millikan [8]	Cohabitant (ever)	p53-	0.8 (0.5-1.3)		ac_4
		p53+	0.8 (0.5-1.2)	0.00(1), NS	
Delfino [31]	Cohabitant (ever)	Premenopausal	2.69 (0.91-8.00)		ac_5
		Postmenopausal	1.01 (0.45-2.27)	2.01(1), NS	
		NAT2 slow acetylator	Data not shown		ac_6
		NAT2 fast acetylator	Data not shown	NS	
Johnson [38]	Home or work (ever)	Premenopausal	2.3 (1.2-4.6)		ac_7r
		Postmenopausal	1.2 (0.8-1.8)	2.64(1), NS	
Rookus [27]	Home or work (ever)	p53 normal	Data not shown		c_8
		p53 overexpressed	Data not shown	NS	
Wartenberg [4]	Spouse (ever)	Age at baseline - <50	1.14 (0.81-1.59)		ac_9es
		50-59	0.96 (0.73-1.26)		
		60-69	1.00 (0.74-1.36)		
		70+	1.06 (0.65-1.75)	0.65(3), NS	
		Age at marriage - <20	1.04 (0.73-1.48)		ac_9es
		20+	1.00 (0.84-1.19)	0.04(1), NS	
Woo [28]	Cohabitant (current)	Premenopausal	2.78 (1.37-5.63)		u
		Postmenopausal	0.91 (0.71-1.18)	8.50(1), p<0.01	
Egan [5]	Home and work (adulthood)	Premenopausal	Data not shown		ac_7
		Postmenopausal	Data not shown	NS	
Kropp [7]	Home or work (lifetime)	NAT2 slow acetylator	1.16 (0.66-2.04)		ac_9t
		NAT2 fast acetylator	1.98 (0.96-4.09)	1.30(1), NS	
Kropp[15]	Home or work (lifetime)	SULT1A1*1/*1 genotype	1.69 (0.89-3.21)		ac_9v
		SULT1A1*2 allele carrier	1.40 (0.74-2.64)	0.17(1), NS	

TABLE 7 - Relative risk of breast cancer in lifelong nonsmoking women according to ETS exposure; subgroup analyses (continued)

Study author [ref][1]	Exposure index (timing)[2]	Subgroup		Relative risk (95% CI)	Heterogeneity[3]	Notes[4]
Gammon [11]	Cohabitant (ever)	Premenopausal		1.21 (0.78-1.90)		ac_7
		Postmenopausal		0.93 (0.68-1.29)	0.89(1), NS	
		Body mass index	<22.3	1.70 (1.00-2.90)		ac_7
			22.3-25.0	0.49 (0.28-0.86)		
			25.1-29.2	1.05 (0.65-1.70)		
			>29.2	1.16 (0.66-2.03)	10.31(3), p<0.05	
		Alcohol	- never	0.99 (0.69-1.41)		ac_7
			- ever	1.13 (0.78-1.64)	0.25(1), NS	
		Use of hormone replacement therapy	- never	1.03 (0.78-1.37)		ac_7
			- ever	1.14 (0.61-2.12)	0.09(1), NS	
		Use of oral contraceptives				
			- never	1.03 (0.74-1.42)		ac_7
			- ever	1.05 (0.69-1.59)	0.01(1), NS	
		Family history of breast cancer	- no	0.98 (0.74-1.30)		ac_7
			- yes	1.49 (0.79-2.82)	1.39(1), NS	
		Age	- <65	1.09 (0.79-1.51)		ac_7
			- 65+	0.91 (0.59-1.41)	0.43(1), NS	
Reynolds [6]	Cohabitant (ever)	Pre/peri-menopausal		0.93 (0.71-1.22)		ac_7r
		Postmenopausal		0.92 (0.78-1.08)	0.01(1), NS	
Shrubsole [12]	Spouse (ever)	Premenopausal		1.0 (0.8-1.3)		ac_7w
		Postmenopausal		0.9 (0.6-1.2)	0.24(1), NS	
	Workplace (last 5 years)	Most recent job				
		- trade		0.96 (0.58-1.58)		$ac_{10}e$
		- service		1.29 (0.41-4.09)		
		- clerical		0.77 (0.40-1.49)		
		- professional actuarial		1.38 (0.87-2.21)	2.38(3), NS	
Hanaoka [14]	Cohabitant (ever)[6]	Premenopausal		1.6 (0.9-2.7)		ac_7x
		Postmenopausal		0.7 (0.4-1.1)	4.71(1), p<0.05	

[1] Studies are identified by the first author of the principal publication

[2] Reference group is all lifelong nonsmokers unexposed to the given source, except where indicated by a reference to other notes

[3] Heterogeneity The chisquared statistic is shown with the degrees of freedom in brackets and then the p value. NS = $p \geq 0.1$

[4] Notes

- a adjusted for age
- c adjusted for other confounding variables as indicated below:
  - c_1 education, family history of breast cancer
  - c_2 race, age at menarche, age at first full-term pregnancy, parity, family history of breast cancer, benign breast biopsy, alcohol
  - c_3 as c_2 plus menopausal status
  - c_4 race, sampling fraction
  - c_5 family history of breast cancer
  - c_6 family history of breast cancer, menopausal status
  - c_7 all variables listed in Table 2 except the subgroup variable
  - c_8 lifetime physical activity, other unspecified confounders
  - c_9 all variables listed in Table 2
  - c_{10} all variables listed in Table 2, and passive smoking from husband
- e estimated from data reported
- u unadjusted
- r relative risks for adult and childhood exposure separately also did not vary significantly by menopausal status (data not shown)
- s relative risks for spouse (current) and spouse (former) also did not vary significantly by age at baseline or by age at marriage (data not shown)
- t relative risks for adult and childhood exposure separately also did not vary significantly by NAT2 acetylation genotype (data not shown)
- v relative risks for adult exposure also did not vary significantly by SULT1A1 genotype (data not shown)

TABLE 7 - Relative risk of breast cancer in lifelong nonsmoking women according to ETS exposure; subgroup analyses (continued/2)

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w relative risks for workplace exposure and for combined spousal and workplace exposure also did not vary significantly by menopausal status (data not shown)

x relative risks for exposure other than at home and for any exposure were also both significantly higher for premenopausal than postmenopausal women. Non-home (2.3 vs 0.4, Heterogeneity $p<0.001$), Any (2.6 vs 0.7, Heterogeneity $p<0.01$)

[5] Exposed for at least 1 hour/day ETS exposure from any source for at least 12 consecutive months during life

[6] Reference group is never exposed at home during life and not exposed daily outside the home at baseline

TABLE 8 – Meta-analyses of breast cancer risk in relation to ETS exposure

Index of exposure (Data source)	Subgroup	N[2]	Fixed-effects Relative risk (95% CI)	Random-effects Relative risk (95% CI)	Heterogeneity[1] Chisquared	DF[3]	p[4]
Spouse (Table 3)[5]	All	8	1.08 (0.97-1.21)	1.20 (0.96-1.49)	18.72	7	<0.01
Spouse or cohabitant (Table 3)[6]	All	19	1.02 (0.97-1.08)	1.08 (0.98-1.18)	37.05	18	<0.01
Workplace (Table 4)[7]	All	5	1.08 (0.94-1.24)	1.14 (0.90-1.46)	10.02	4	<0.05
Any adult (Table 4)[8]	All	6	1.13 (1.02-1.25)	1.19 (1.00-1.42)	11.54	5	<0.05
Child (Table 5)[9]	All	9	0.99 (0.91-1.07)	0.99 (0.91-1.07)	7.64	8	NS
Total (Table 6)	All	6	1.44 (1.21-1.72)	1.54 (1.17-2.04)	11.14	5	<0.05
Various (Table 7)	Premenopausal	10	1.21 (1.05-1.40)	1.54 (1.16-2.05)	25.10	9	<0.01
	Postmenopausal	10	0.96 (0.87-1.07)	0.98 (0.86-1.12)	11.47	9	NS
	Ratio pre/post	10	1.32 (1.09-1.60)	1.50 (1.12-2.00)	15.81	9	<0.1
Principal[10]	All	22	1.05 (0.99-1.11)	1.12 (1.02-1.24)	48.71	21	<0.001
	Prospective	9	1.00 (0.94-1.07)	1.02 (0.93-1.10)	10.74	8	NS
	Case-control	13	1.16 (1.05-1.28)	1.28 (1.07-1.53)	32.12	12	<0.01
				(Between study type	*5.85*	*1*	*<0.05)*
	N.America	11	0.99 (0.93-1.06)	1.02 (0.93-1.13)	17.46	10	<0.1
	Asia	6	1.08 (0.94-1.24)	1.09 (0.90-1.33)	8.36	5	NS
	Europe	5	1.37 (1.17-1.60)	1.50 (1.14-1.97)	8.89	4	<0.1
				(Between continent	*14.02*	*2*	*<0.001)*
	>500 cases	7	1.00 (0.93-1.06)	1.01 (0.93-1.09)	7.54	6	NS
	<500 cases[11]	13	1.18 (1.05-1.33)	1.27 (1.03-1.57)	33.35	12	<0.001
				(Between study size	*5.94*	*1*	*<0.05)*
	9+ confounders	9	0.99 (0.93-1.06)	1.05 (0.93-1.19)	20.61	8	<0.01
	<9 confounders[12]	11	1.20 (1.08-1.35)	1.23 (1.03-1.45)	19.31	10	<0.05
				(Between adjustments	*8.21*	*1*	*<0.01)*

[1] Heterogeneity relates to variation between studies within subgroup, except for results given in italics which relate to heterogeneity between subgroups

[2] N number of studies in meta-analysis

[3] DF degrees of freedom

[4] p expressed as <0.001, <0.01, <0.05, <0.1 or NS ($p \geq 0.1$)

[5] Index includes "partner". Spouse (ever) is chosen for preference where multiple results are available

[6] First relative risk cited for each study in Table 3

[7] Index includes "not home"

[8] Index includes "home or workplace"

[9] First relative risk cited for each study in Table 5

[10] Based on relative risks marked with an "m" in the notes column in Tables 3, 4 and 6

[11] The number of cases in nonsmokers was not known for two studies (see Table 3)

[12] Two studies were excluded as the number of confounding variables adjusted for other than age was not clear (see Table 2)

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