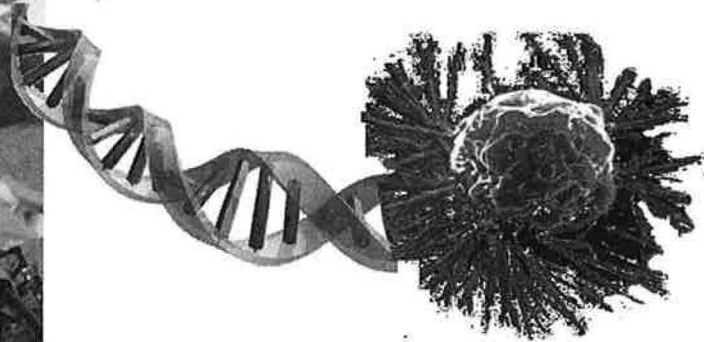


Lifestyle, Genes, and Cancer



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Cancer epidemiology, traditional and molecular

Prevention of breast cancer and its progression

Role of lifestyle and genetics in cancer prevention

Introduction

It is estimated that almost 1 ½ million people in the United States (US) are diagnosed with cancer every year.¹ There is also evidence that lifestyle factors increase cancer risk and if modified could significantly reduce the cancer burden.² This review contains the current epidemiological evidence on the contributions of the major modifiable risk factors to cancer incidence and mortality for the most common cancers diagnosed in the US and developed world - breast, colorectal, lung, and prostate cancer.³

Due to the substantial effect of modifiable lifestyle factors on the most prevalent cancers, it has been estimated that 50% of cancer is preventable.⁴ Current recommendations for the major risk factors that can be modified to decrease risk for these cancers include reducing tobacco use, increasing physical activity, controlling weight, improving diet, and limiting alcohol consumption.⁵ When defining the cancer prevention strategies used to modify these risk factors, it is also important to integrate genetic information that may play a role in determining the effectiveness for modifying these factors.

Breast Cancer

Breast cancer is the most common cancer in women, with almost 180,000 women diagnosed with breast cancer in the US annually.¹ The fact that lifestyle changes can decrease the risk for developing breast cancer is supported by several lines of evidence. First, studies indicate that as populations migrate from the low- to the high-risk geographical areas for breast cancer, the incidence of breast cancer approaches that of the host country in one to two generations.⁶⁻⁸ Secondly, only a small part of breast cancer risk is linked to the inheritance of genetic abnormalities, and environmental exposures from chemicals or physical agents. Thirdly, modification in lifestyle due to behavior change has been shown to be associated with a lower breast cancer risk in population studies. Lastly, experimental animal and human models provide confirmation that several lifestyle behaviors have a positive effect on breast biology. The major modifiable risk factors for breast cancer are physical inactivity, obesity and the overweight condition, alcohol use, and possibly diet.⁹

Physical Activity

A recent systemic review that included all cohort and case-control studies that assessed total and leisure time activities in relation to the occurrence or mortality of breast cancer indicated that there was strong evidence for an inverse association between physical activity and breast cancer risk.¹⁰ The risk reduction for the cohort studies with a higher quality score ranged from 21% to 39%. Evidence for an inverse dose-response relationship was seen in all but one of the cohort studies. The risk reduction for the case-control studies ranged from 23% to 65%, and evidence for a dose-response was noted in most of the case-control studies. A lower risk for breast cancer was also noted for both premenopausal and postmenopausal breast cancer in nearly all of the studies in which this relationship was assessed. Several of these studies quantified the level of physical activity required to reduce breast cancer risk, finding that this risk reduction was on the average about 30% lower for women who exercised for 3-4 hours per week at moderate and vigorous levels. In addition, most studies have been conducted in non-Hispanic white women, although data from some studies suggest that physical activity is associated with a lower risk for breast cancer in women of diverse races and ethnicities.¹¹⁻¹⁵ Physical activity at adolescence has also been observed to be associated with a delayed age at breast cancer onset among women with mutations in the tumor suppressor genes (TSGs), *BRCA1* and *BRCA2*, which substantially increase the risk for breast cancer.¹⁶ Likewise, the

benefit of physical activity has been apparent among breast cancer survivors in recent studies.^{17, 18} In one study that involved 2,987 women diagnosed with stages I, II, and III breast cancer, the age-adjusted risk of death from breast cancer was inversely associated with physical activity after the diagnosis of breast cancer.¹⁷ In this study, the greatest benefit was noted in women who performed the equivalent of walking 3-5 hours per week at an average pace. In another study, among 1,264 women ages 20 to 54, it was found that recreational physical activity undertaken in the year before a diagnosis of breast cancer was associated with a lower all-cause mortality at the 8-10 year follow-up.¹⁸ Thus, it appears that physical activity may play an important role in preventing breast cancer in women with and without a personal history of breast cancer, as well as delaying the onset of breast cancer in women with genetic susceptibility.

It is thought that the relationship between physical activity and breast cancer risk may have a hormonal mechanism. Increased physical activity measured through self-report has been found to be associated with lower estrogen levels in premenopausal and postmenopausal women.^{19, 20} Exercise interventions have also been shown to decrease estrogen levels and increase sex hormone-binding globulin (SHBG) levels in postmenopausal women.^{21, 22} A recent pooled analysis of nine cohort studies showed that the risk for breast cancer in postmenopausal women increased significantly with increasing concentrations of total estradiol, free estradiol, and estrone.²³ In addition, lower concentrations of SHBG, which binds to estradiol, is associated with a higher risk for breast cancer.²³ Other findings from epidemiological studies further support the etiologic role of estrogen in breast cancer, showing that breast cancer risk is associated with early menarche, late menopause, low parity, and the use of exogenous estrogens, all of which are linked to prolonged or extensive exposure of breast tissue to estrogen stimulation.²⁴ High endogenous estrogen levels have also been shown to be associated with shortening of the disease-free interval in postmenopausal women with breast cancer recurrence.²⁵ Finally, a number of clinical trials have shown that estrogen ablation increases survival after a diagnosis of breast cancer.²⁶ In addition, estrogens can increase the production of insulin-like growth factor I (IGF-I),²⁷ and higher estrogen and IGF-I levels have both been shown to be associated with increased mammographic density.²⁸ Mammographic density is a strong risk factor for breast cancer, and reflects proliferation of the breast epithelium and stroma.²⁹ Several epidemiological studies have shown that IGF-I is positively associated with breast cancer risk, especially in premenopausal women.³⁰⁻³³ Thus, several randomized studies with exercise interventions have been performed to identify the potential benefit of aerobic exercise or strength training for reducing IGF-I levels. These studies have shown that aerobic training produces a decrease in mean serum IGF-I levels in prepubertal girls,³⁴ adolescent females,³⁵ and postmenopausal breast cancer survivors.³⁶ Whereas, most of the weight training intervention studies that involved premenopausal postmenopausal women or premenopausal and postmenopausal breast cancer survivors, reported no change in IGF-I levels.³⁷⁻³⁹

Although there is considerable epidemiological and clinical evidence that link cumulative and sustained exposure to estrogens with the increased risk of developing breast cancer,²⁴⁻²⁶ as presented above, there is no clear understanding of the mechanisms through which estrogens cause breast cancer. The most widely acknowledged potential mechanism for estrogen carcinogenicity is its binding to its specific nuclear receptor, estrogen receptor alpha (ER- α), exerting a potent stimulus on breast cell proliferation.⁴⁰ However, that fact that ER- α knockout mice expressing the *Wnt-1* oncogene (*ERKO/Wnt-1*) also develop mammary tumors indicates that estrogen may cause breast cancer through a non-ER- α -mediated mechanism.⁴⁰ Experimental studies on estrogen metabolism have shown that estrogen metabolites, produced by cytochrome P450-mediated activation, form DNA-adducts that can generate DNA mutations that initiate breast cancer.⁴¹ However, to date, there are no studies that have produced

definitive evidence that DNA damage in human breast tissue due to the formation of estrogen DNA-adducts contributes to the initiation or progression of breast cancer.⁴¹ On the other hand, there is now considerable evidence that is increasing to suggest that estrogens play an important role in the etiology of breast cancer by silencing genes implicated in breast carcinogenesis.⁴²⁻⁴⁴ For breast cancer, as well as many other cancers, promoter region hypermethylation of TSGs is an early and frequent event in carcinogenesis and occurs in conjunction with transcriptional silencing of these genes. The mechanism driving promoter hypermethylation is unknown, however, it has been noted in tissues where there is chronic exposure to carcinogens that a continuum of increasing gene promoter hypermethylation occurs from hyperplasia through invasive carcinoma.⁴⁵ The process of promoter hypermethylation has been referred to as “epigenetic” and is potentially reversible.⁴⁶ DNA-methylation of promoter CpG islands of genes prevents them from being transcribed for apoptosis, senescence, and other important physiological processes in cells, which makes cells that have accumulated DNA-methylation prone to becoming tumor cells.⁴⁶ Although the details of the relationship between estrogen, and the methylation of genes are unknown, there is evidence that estrogen alters the methylation patterns of genes. Studies in mice have shown that diethylstilbestrol (DES)⁴⁷ and estradiol⁴⁸ elicit genetic methylation changes that result in heavier uteri⁴⁷ and uterine tumors.⁴⁸ Recently, it was also demonstrated that estradiol and DES induced promoter hypermethylation of the putative TSGs, *E-cadherin* and *p16*, in human breast epithelial cells.⁴²

There is direct evidence that promoter hypermethylation of several putative TSGs, including *APC*, *RASSF1A*, and *RARβ2*, is associated with breast carcinogenesis.^{45, 49-56} In a recent study that included women with and without a personal history of breast cancer, it was shown that promoter hypermethylation of *APC*, *RASSF1A*, and *RARβ2* in non-malignant breast tissue was associated with epidemiological markers of breast cancer risk.⁵⁶ More specifically, *APC* and *RASSF1A* were positively associated with breast cancer risk, as defined by the Gail mathematical risk model.⁵⁷ Whereas, promoter hypermethylation of *RARβ2* was positively associated with a personal history of breast cancer.⁵⁷ Several studies,^{51, 52, 58-60} have shown that treatment of breast cancer cells with promoter hypermethylation of the putative TSGs, *RASSF1A* and *RARβ2*, with the DNA methyltransferase inhibitor 5-Aza-2'-deoxycytidine has led to their demethylation and re-expression. Thus, promoter hypermethylation of TSGs can be reversed by small molecules, making them promising targets for cancer prevention interventions. Alternatively, it is thought that lifestyle changes, such as physical activity, may reverse promoter methylation of TSGs. A recent cross-sectional study was conducted to determine the association of lifetime physical activity with promoter hypermethylation of *APC* and *RASSF1A* in non-malignant breast tissue, among premenopausal and postmenopausal women without breast cancer.⁶¹ This study provided evidence to support the hypothesis that physical activity is inversely associated with promoter hypermethylation of TSGs, such as *APC*, in non-malignant breast tissue.⁶¹

In summary, observational studies have shown that there is a strong inverse association between moderate or vigorous physical activity and breast cancer risk, in which there may be a hormonal mechanism, particularly involving estrogen and its related effect on IGF-I.

Obesity and Overweight

The association of the overweight condition and obesity with breast cancer risk has been well studied. Extensive data from cohort and case-control studies provide convincing evidence that there is a 30-50% greater risk of postmenopausal breast cancer from the overweight condition and obesity, and a larger two-fold increase in risk for adult weight gain.^{62, 63} Estimates from a meta-analysis of cohort studies found gradual increases in the risk of postmenopausal

breast cancer up to a body mass index (BMI) of 28, after which the risk did not increase further, with the relative risk of 1.26 for a BMI of 28 compared with a BMI of less than 21.⁶⁴ However, risk estimates have been found to vary by age at diagnosis, history of hormone replacement therapy (HRT), and estrogen receptor (ER) status of the tumor. Another meta-analysis, involving prospective cohort and population-based case-control studies, found that this increased risk for postmenopausal breast cancer corresponded to a 12% increase for overweight women and a 25% increase for obese women.⁶⁵ In fact, in a prospective cohort study among premenopausal and postmenopausal women, there was an even stronger association for adult weight gain, with a doubling of risk among women who have never used HRT and who gained over 20 kg from age 18.⁶⁶ A meta-analysis of cohort studies found an inverse association between BMI and premenopausal breast cancer, with a relative risk reduction of 46% for women with a BMI greater than 31 compared with a BMI of less than 21.⁶⁴

There are several plausible mechanisms linking adiposity to breast cancer risk. These mechanisms have evolved from a focus on estrogen excess, to the combined effect of estrogen and progesterone, and most recently, to attempts to understand the factors defining the bioavailability and effects of estrogens and androgens and their metabolites on specific end organs. Increases in obesity have been associated with increases in androgens, triglycerides, and insulin; and decreases in SHBG. These hormonal changes increase the bioavailability of estradiol and its metabolites and may also directly promote tumor growth.⁶⁷⁻⁷³ The bioavailability of estradiol is dependent on the degree and strength of binding to several protein carriers. SHBG is the predominant protein carrier of estradiol and the percentage of free estradiol is inversely related to the level of SHBG.²³ Increases in free fatty acids, such as triglycerides, has been reported to increase the level of free estradiol by displacing estradiol from SHBG.²³ Therefore, both decreases in SHBG and increases in triglycerides may result in increases in free estradiol. Key and Pike^{74,75} first hypothesized that the effect of adiposity on the estrogen bioavailability was modulated by menopausal changes in estrogen and progesterone production, and as a result explained the contradictory findings for premenopausal and postmenopausal breast cancer. Before menopause, ovarian production of estrogen overwhelms changes in estrogen metabolism related to the overall level of adiposity. As a result, estradiol in ovulatory cycles does not differ significantly in obese compared to lean women. However, estradiol levels are reduced in anovulatory cycles that are more frequent in obese than lean premenopausal women. In addition, obese premenopausal women have been found to have markedly reduced progesterone levels, both due to anovulation and decreased production during the luteal phase of the menstrual cycle. After menopause, the lower risk associated with premenopausal obesity diminishes over time. In addition, in postmenopausal women, the overall level of adiposity results in increased estrogenic activity due to an increase in estrogen production from the aromatization of higher levels of androgens in adipose tissue,⁷⁶ decreased estrogen binding⁷⁷ due to decreases in SHBG,^{70,72,78} and increases in triglycerides.⁷² Furthermore, insulin and insulin-like growth factors have been found to promote cancer cell growth, and their production can be increased by estrogen.⁷⁹ However, although five studies have shown that higher IGF-I levels are associated with a higher risk for breast cancer,⁸⁰⁻⁸⁴ only one of these studies found this association to be statistically significant.⁸¹ In addition, published studies, thus far, have not found an association between IGF-I and postmenopausal breast cancer.^{81,83,85} Similarly, one of two published studies found C-peptide, a marker of hyperinsulinemia, to be associated with breast cancer risk.^{85,86} Data on the association between IGF-I and BMI or fat mass in men and women are also mixed,⁸⁷ with some studies showing no association and others an inverse association. Therefore, it has been hypothesized that IGF-I is positively associated with muscle mass, which may explain the increased premenopausal breast cancer risk among tall and lean women. Another hormonal hypothesis is that leptin, a hormone that reflects total fat mass, may be positively related to breast cancer risk.

Leptin has been characterized as a growth factor for breast cancer.⁸⁸⁻⁹¹ Thus far, one study has been published that has examined this relationship among premenopausal women finding non-significant lower levels of leptin in breast cancer cases compared to controls,⁹² which is consistent with an inverse association between BMI and premenopausal breast cancer. There have been no published studies that have examined the relationship of leptin to breast cancer risk in postmenopausal women. Thus, current studies do not provide convincing data to support a link between insulin, IGF-I, or leptin with breast cancer risk. However, one study found that there was a multiplicative interaction between adult exercise and sports activity and BMI, with inactive women in the upper BMI quartile being at increased risk compared with their lean and active counterparts.⁹³

Alcohol

The literature over the last 2 ½ decades provides convincing evidence that alcohol consumption has a modest impact on breast cancer risk.⁹⁴ That is, the relative risk (RR) associated with alcohol consumption is not great, since it has been found to be associated with an approximately 10% increase in risk for an increase in average consumption of one drink per day.⁹⁵ However, because of the high prevalence of alcohol consumption, the attributable risk is likely to exceed 10% in those who consume alcohol regularly.⁹⁶ The dose-response relationship between alcohol and breast cancer risk is well demonstrated in the results of a meta-analysis by Smith-Warner and colleagues,⁹⁵ where breast cancer risk rose by 7 percent for every 10-gram increase in daily alcohol consumption. However, there is also some evidence that this risk does not substantially increase until a threshold of 15 grams a day of alcohol is reached. Furthermore, there is little evidence that this risk is modified by menopausal status.^{97, 98}

One plausible explanation for an etiologic association between alcohol and breast cancer carcinogenesis is that it increases circulating estrogen levels. Circulating estrogens originate from ovarian synthesis or from peripheral conversion (aromatization) pathways involving androgens, such as testosterone. For premenopausal women, alcohol intake has been associated with higher concentrations of estrogens and androgens, as well as decreases in follicle-stimulating hormone levels.⁹⁹⁻¹⁰⁶ It has also been found that in postmenopausal women not using HRT that moderate alcohol intake can lead to increased estrogen and androgen levels, although the findings have been variable.¹⁰⁷⁻¹⁰⁹ Studies have shown that alcohol is associated with mammographically dense breast tissue,¹¹⁰⁻¹¹⁵ which is also positively associated with levels of estrogen and IGF-I.^{27, 116} As previously mentioned, estrogen can increase the production of IGF-I.²⁷ The dense patterns seen on mammography are associated with atypical hyperplasia and/or carcinoma insitu¹¹⁷ and with cytological atypia in nipple aspirates,¹¹⁸ which may be a result of mitogenesis or mutagenesis in the breast.¹¹⁹

In addition, whether dietary and genetic factors modify the effect of alcohol use in breast cancer risk has been of interest. Zhang and colleagues reported that women consuming more than 15 grams of alcohol per day and whose intake of folate was less than 300 micrograms per day had a higher risk for breast cancer, compared with women that had the same level of alcohol consumption, along with folate levels greater than 300 micrograms per day.¹²⁰ Other reports¹²¹⁻¹²³ confirm this relationship. It is important to note though that low-to-moderate alcohol consumption, in contrast to heavy drinking, may not result in folate depletion.¹²⁴⁻¹²⁷ Thus, it is thought that in combination with low folate intake, ethanol and/or its primary metabolite acetaldehyde may alter folate or methionine metabolism so that an imbalance in DNA methylation or in DNA repair processes results; leading to DNA instability or aberrant gene expression.¹²⁸⁻¹³² Alcohol consumption also has been associated with decreased blood levels of β -carotene, lutein/zeaxanthin, and vitamin C, which are thought to be cancer protective.^{133, 134}

Thus, these studies collectively suggest that alcohol consumption, particularly at higher levels, may be associated with increased breast cancer risk, in part because of the negative impact of alcohol intake on the dietary factors that are thought to be cancer-protective. There is also some evidence that the relationship between alcohol with breast cancer risk could differ according to the genotype of several metabolizing enzymes. Park and colleagues have found that premenopausal women that consume alcohol and lack the *glutathione-S-transferase* genes (*GSTM1* and *GSTT1*) were at 5.3 fold greater risk for developing breast cancer compared with women with these genes, suggesting that the lack of these genes potentiates the adverse effects of alcohol on the breast due to the decreased capacity to detoxify alcohol.¹³⁵

Diet

Fat is the dietary component that has most often been found to relate to the risk of cancer in general.¹³⁶ In a pooled analysis of case-control studies, a highly significant and positive association was seen between dietary fat and breast cancer risk.¹³⁷ However, prospective studies have consistently shown no association.¹³⁸ In a pooled analysis of large prospective studies, breast cancer risk for a higher total fat intake was minimal (RR = 1.03).¹³⁹ Similarly, the largest randomized controlled dietary cancer prevention intervention study to date that involved 48,800 postmenopausal women found only a modest statistically nonsignificant 9% decrease in invasive breast cancer in those that consumed a low fat diet.¹⁴⁰

Early epidemiological studies suggested that vegetables and fruits may lower breast cancer risk.¹⁴¹ However, a pooled analysis of eight prospective cohort studies involving 351,825 women found no association between the intake of vegetables and fruits and breast cancer risk.¹⁴² A recent prospective study in which 285,526 women participated, ages 25-70 years, found no significant association between vegetable and fruit intake and breast cancer risk, adjusting for potentially important confounders, such as menopausal status.¹⁴³ Although these studies collectively indicate that vegetables and fruits may not modify breast cancer risk, it is possible that specific genotypes may interact with vegetable and fruit intake to lower breast cancer risk. A recent large case-control study was performed to assess the effect of different variants of myeloperoxidase (MPO), an antimicrobial enzyme in the breast, which generates reactive oxygen species, on breast cancer risk. This study showed that specific variants of MPO were associated with a lower breast cancer risk among premenopausal and postmenopausal women who consumed higher amounts of vegetables and fruits that was not noted among the lower consumption group.¹⁴⁴

Soy products contain phytoestrogens which can act as weak estrogens and as estrogen antagonists, depending on the hormonal milieu of the host. Epidemiological data suggest that the consumption of soy products may reduce breast cancer risk.^{145,146} However, recent evidence suggests that a component of soy, genistein, may promote the growth of some estrogen-sensitive tumors and reduce the efficacy of tamoxifen, emphasizing the need to perform additional studies to determine whether soy products are safe for women with breast cancer or at high risk for breast cancer.^{147, 148}

Several epidemiological studies have investigated the association between dietary and supplement intakes of various vitamins and minerals and the risk of breast cancer. Those micronutrients that have been found to be potentially associated with a lower risk for breast cancer include the carotenoids, folate particularly in association with alcohol intake, calcium, vitamin D, and vitamin C.^{141, 149-151}

Colorectal Cancer

Colorectal cancer is the second most commonly occurring cancer in the US and was estimated to affect over 150,000 men and women in 2005.¹ Based on epidemiological studies, there is convincing data that obesity is an important risk factor for colorectal cancer,¹⁵² and that a high level of physical activity is a strong protective factor for colorectal cancer, which may reduce its risk by 50%.^{153, 154} Convincing data from epidemiological studies also support tobacco use as significant risk factor for colorectal cancer. Another potential risk factor for colorectal cancer is the consumption of red meat. However, the numerous studies with both cohort and case-control designs have not consistently supported a positive association between the consumption of red meat and colorectal cancer. On the other hand, a dietary factor that may be related to colorectal cancer risk is the micronutrient, folate, with an inverse association.

Physical Activity

Colorectal cancer is one of the most commonly studied cancers with respect to physical activity. Numerous case-control and cohort studies have found an inverse association between physical activity and colon cancer risk.^{152, 155-159} This relationship has been observed in men and women of all age groups, in various racial and ethnic groups, and in diverse geographic areas around the world. In some of these studies the effect of physical activity on colon cancer risk is attenuated in women compared to men, the reason for which is unknown. In most of the cohort studies described in a past review,¹⁵² as well as several more recent cohort studies,¹⁵⁵⁻¹⁵⁹ the risk of colon cancer was decreased in the highest physical activity compared with the lowest category, with risk reductions ranging from 10% to 60%. In addition, adjustment for potential confounding factors, such as age, diet, and obesity did not reduce the strength of the associations between physical activity and colon cancer risk.^{152, 155-159} However, with regard to rectal cancer, these studies as a whole did not support an inverse association between physical activity and rectal cancer risk.^{152, 155-159} There is also some evidence that physical activity reduces neoplastic growth in the colon and rectum. In a recent prospective cohort study, among African-American women, higher levels of physical activity were inversely associated with risk for the development of colorectal adenomas,¹⁶⁰ which are thought to be precursors to most colon and rectal cancers.¹⁶¹ In another recent study, a 12-month moderate-to-vigorous intensity aerobic exercise intervention resulted in a significant decrease in colon crypt cell proliferation indices in men who exercised ≥ 250 min/wk or whose cardiopulmonary fitness, as measured by VO_2 max, increased by $\geq 5\%$.¹⁶² In this study, patients with colon cancer and persons with an elevated risk for colon cancer (history of sporadic adenoma, ulcerative colitis, familial polyposis, family history of colon cancer, age, etc.) exhibited in macroscopically normal colon mucosa both an increased epithelial cell proliferation rate and an extension of the normal zone of epithelial cell proliferation extending from the base to the luminal portion of the colonic crypt.¹⁶³

Biological mechanisms for the effect of physical activity on colon and perhaps rectal cancer risk are unknown. However, several biologically plausible mechanisms have been proposed including alterations in the immune system, reduced bowel transit time (increasing exposure to fecal carcinogens), higher prostaglandin levels, and bile acid secretion, as well as higher levels of insulin and insulin-like growth factors.¹⁶⁴ Although, studies are limited in number, there is convincing data to support the latter of these mechanisms, in that both insulin and IGF-I are potent mitogens of colonic carcinoma cells. Several studies have now shown that high levels of IGF-I increase the risk for colorectal cancer, whereas high levels of insulin growth factor binding protein-3 (IGFBP-3), which can reduce IGF-I levels, are associated with a reduced risk for colorectal cancer.^{165, 166} Likewise, the interaction of physical activity with

inherited genetic polymorphisms or mutations in colorectal tumors is limited. Although the interaction of gene polymorphisms and physical activity are unavailable, there is evidence that mutations in the genes, *APC*, *p53*, and *Ki-ras*, may be inversely associated with physical activity. These genes are thought to regulate cell growth and apoptosis with mutations in these genes resulting in tumor growth.¹⁵⁵ *APC* mutations are thought to be an early event in colorectal carcinogenesis, with other gene mutations occurring afterwards.¹⁵⁵ Studies have not been done to determine the association of physical activity with *APC* mutations, but other studies have suggested that *p53* and *Ki-ras* mutations in colorectal tumors may be inversely related to physical activity.^{167, 168} Another study examined physical activity with colorectal adenomas and reported that more active people were more likely to have *Ki-ras* negative rather than *Ki-ras* positive colorectal tumors.¹⁶⁹

Obesity and Overweight

Numerous cohort and case-control studies have consistently demonstrated a positive relationship between body size and colorectal cancer. This relationship has been observed in men and women with the risk being stronger for men than women.¹⁵² In these studies, this relationship is stronger for those who are obese as compared to those who are overweight. In general, this relationship has also been proven to be stronger for cancer of the colon than the rectum, and for the distal rather than the proximal colon. Body size has also been shown to influence colorectal carcinogenesis: BMI has been found to be associated with colorectal adenoma, a precursor lesion of colorectal cancer, and large adenomas of the distal colon and rectum in several epidemiological studies.¹⁷⁰⁻¹⁷⁷ There is also evidence to suggest that abdominal or visceral adiposity is a risk factor for colorectal cancer independent of BMI. Recent studies have shown that higher waist-to-hip ratio (WHR) increases the risk for colorectal cancer.¹⁷⁸⁻¹⁸⁰

Understanding the biological mechanisms linking body size to colorectal cancer is evolving. One plausible mechanism is that a high BMI causes insulin resistance, which promotes colon carcinogenesis. The term insulin resistance refers to a state of cellular unresponsiveness to the effects of insulin with higher levels of insulin required to normalize plasma glucose, which is associated with a high BMI.¹⁸¹ Diabetes mellitus type-2 is a disease that occurs when insulin resistance coincides with impaired pancreatic secretion of insulin, and is positively associated with colorectal cancer. Type-2 diabetics have a 3-fold increased risk for colorectal cancer compared to nondiabetics,¹⁸² and in general, non-obese colorectal cancer patients exhibit clinical manifestations of insulin resistance, with higher insulin and glucose levels compared to their controls.¹⁸³ Furthermore, serum levels of C-Peptide (the cleaved product of proinsulin and a marker of insulin secretion), glycated hemoglobin, and glucose have all been positively associated with colorectal neoplasia.¹⁸⁴⁻¹⁸⁸ In addition, plasma levels of IGF-I, which can be increased by insulin, has been positively associated with colorectal cancer.¹⁸⁹ Furthermore, several metabolic disturbances as the result of the insulin resistant state, including hyperinsulinemia, hyperglycemia, hypertriglyceridemia, and increased levels of non-esterified fatty acids have been found to be positively associated with colorectal cancer risk among fasting participants in prospective studies.^{190, 191} At least three mechanisms exist through which insulin resistance may cause colorectal cancer. The first is that insulin promotes the growth of colorectal tumors. Specifically, insulin has been shown to stimulate cellular proliferation and reduce cellular apoptosis in colorectal cancer cell lines,^{192, 193} and it promotes colorectal cancer growth in animal models.¹⁹⁴⁻¹⁹⁶ Secondly, insulin increases IGF-I levels, and high circulating levels of IGF-I have been associated with colorectal cancer risk.^{189, 197, 198} IGF-I has also been shown to promote the growth of colon cancers in a mouse model.¹⁹⁹ In addition, obesity is associated with a state of chronic inflammation, thought to be induced by high circulating levels

of lipids and glucose, both of which create a pro-inflammatory environment that contains a high free radical content.^{200, 201} It is well known that inflammatory bowel disease increases the risk for colorectal cancer.²⁰² In addition, randomized clinical trials have shown that the use of the non-steroidal anti-inflammatory drugs, celecoxib and aspirin, reduce colorectal cancer risk,^{203, 204} where a 45% risk reduction was noted with the use of aspirin for adenoma recurrence.²⁰⁴ Finally, there is some evidence that the association of body size with colorectal cancer may be mediated through other disease pathways. One study reported that an elevated BMI was associated with a mutation of Ki-ras in colorectal tumors, which was more likely to occur in women than men.²⁰⁵

Diet

Although not entirely consistent, numerous case-control and cohort studies have reported a positive association between red meat consumption and processed meat in particular, with colon cancer risk that was not noted with poultry and fish intake. Red meat intake is thought to increase the risk for colorectal cancer due to its higher heme content compared with the white meats, poultry and fish.^{206, 207} Heme damages the colonic mucosa and stimulates epithelial cell proliferation in animal studies.²⁰⁷ Both the ingestion of red meat and heme iron supplementation have been found to increase fecal concentrations of N-nitroso compounds²⁰⁹ and DNA-adducts in human colonocytes.^{208, 209} The central role for DNA adducts in carcinogenesis has been established and confirmed as a biological fact for over 50 years.²¹⁰ Nitrosamines have also been detected in foods with added nitrates or nitrites, such as processed meat.^{211, 212} A meta-analysis of case-control and cohort studies that were published during 1973-1999 assessed the hypothesis that the consumption of red meat and processed meat increases colorectal cancer risk. This study indicated that the RR (higher versus lowest category) for red meat was 1.27 and for processed meat was 1.59.²¹³ A recent prospective cohort study that included 148,610 adults also assessed the effect of long-term red meat and processed meat, as well as poultry and fish consumption, on colorectal cancer risk.²¹⁴ In this study, the risk of distal colon cancer was positively associated with the consumption of processed meat (RR = 1.50), and the risk of rectal cancer was positively associated with the consumption of red meat (RR = 1.71). In contrast, a lower risk of proximal and distal colon cancer was noted with the long-term consumption of poultry and fish in this study.²¹³

Folic acid deficiency has long been known to cause tumors in animals that is thought to be the result of altering gene expression through DNA methylation or by increasing the incorporation of uracil in DNA.²¹⁵ There is considerable evidence from case-control and cohort studies that supports an inverse association between folate intake and colon cancer risk,²¹⁶ with this association being stronger among alcohol users.²¹⁷ A recent study indicated that the inverse association between dietary folate intake and colon cancer risk was stronger for ever smokers compared to never smokers.²¹⁸ A positive association between a functional polymorphism in the folic acid metabolizing gene, methylene tetrahydrofolate reductase, and the incidence of colon cancer adds support to the potential casual relationship between folic acid deficiency and colon cancer.²¹⁹

Tobacco

In 2004, the US Surgeon General recently concluded that the evidence for the relationship of smoking with colorectal cancer was suggestive but not sufficient to infer a causal relationship.²²⁰ At the time of this report, three prospective cohort studies²²¹⁻²²³ and thirteen case-control studies,²²⁴⁻²³⁵ with the exception of the study by Kato and colleagues, identified the RR estimates between smoking and colorectal adenomatous polyps to be between 1.5 to 3.8,

after adjusting for age and other important covariates.²³⁶ However, in a more recent study,²³⁷ the tobacco use of 4,383 subjects with histologically verified benign (hyperplastic or adenomatous) polyps of the distal colon were compared with the tobacco use among 33,667 subjects who were endoscopy negative for distal colon tumors in the screening arm of a randomized trial of flexible sigmoidoscopy. In this study, the risk estimated by the OR was 4.4 for hyperplastic polyps, 1.8 for adenomas only, and 6.2 for both hyperplastic and adenomatous polyps, which provides stronger support for the positive relationship between smoking and colorectal cancer.

Prospective studies that have investigated the relationship between smoking and colon cancer have generally reported RR estimates of 1.2-1.4 for colon cancer and 1.4-2.0 for rectal cancer.²³⁸⁻²⁴⁴ To date, there has not been a meta-analysis that has evaluated this relationship across all studies that controlled for factors that influence colorectal cancer risk.

Recent studies indicate that variants of the metabolizing genes, *NAT1*, *CYP1A1*, *GSTM1*, and *GSTT1*, may interact with smoking to increase the risk of colorectal cancer.²⁴⁵⁻²⁴⁷

Lung Cancer

Lung cancer is the leading cause of cancer death for men and women in the US; 85% of patients who develop lung cancer will die from it within 5 years of diagnosis.²⁴⁸ Although more than 80% of lung cancer cases are attributable to cigarette smoking, recent studies have noted a protective effect for lung cancer with physical activity in men and women after adjusting for smoking.⁵ Past case-control and large cohort studies among men and women were encouraging as to the potential benefit of vegetable and fruit consumption reducing lung cancer risk,⁵ however, this inverse relationship has not held up in more recent studies.²⁴⁹ Thus, there is likely a major benefit for men and women for modifying their lifestyle related to cigarette exposure, and possibly physical activity and fruit and vegetable intake.

Tobacco

Cigarette smoking is more strongly associated with lung cancer than with any other cancer type. Cigarette smoking is also the strongest risk factor for lung cancer, increasing the risk of this disease by at least 10-fold and as much as 20-fold, depending on smoking habits and the medical history. There is also a dose-response relationship between smoking and lung cancer that relates to the number of cigarettes smoked, the deepness of the inhalation of cigarette smoke, and the duration of smoking.²⁵⁰ The median delay between the initiation of smoking and death from lung cancer is approximately 50 years.²⁵¹ Cigarette smoking is more strongly associated with squamous and small-cell lung carcinomas, but is increasingly becoming associated with adenocarcinoma and large-cell carcinomas that are usually located in the periphery of the lung.²⁵² The incidence of adenocarcinoma has increased in many industrialized countries since the 1970s, which is thought to be due to the introduction of filter-tip cigarettes and reconstructed tobacco in the 1950s.²⁵² There is also increasing evidence suggesting that there are significant differences in lung cancer susceptibility and histological type between the sexes. It appears that women may be more susceptible to lung cancer development than men with and without cigarette smoke exposure, and that the histological distribution of lung cancer differs between men and women, with adenocarcinoma being more common in women than men. Studies are underway to determine if genetic variation, as well as biological factors may play a role in these differences between the sexes related to lung cancer histological type and overall risk.²⁵³

Tobacco products contain a diverse array of chemical carcinogens, which are responsible for the development of lung cancer and other cancers. More than 60 known carcinogens have been detected in cigarette smoke.²⁵⁴ These include polycyclic aromatic hydrocarbons (PAH), tobacco-specific nitroamines and other nitrosamines, aromatic amines, aldehydes, volatile hydrocarbons such as benzene, 1,3 butadiene and ethylene oxide, and inorganic compounds.²⁵⁴ Tobacco carcinogens and their metabolically activated forms induce gene mutations through the formation of DNA adducts, which disrupt cell cycle checkpoints and cause genetic instability that predisposes to the development of malignancy.²⁵⁵ It has been shown that activation of tobacco carcinogens via multiple forms of the cytochrome P450 enzyme system, which detoxifies drugs and toxic compounds primarily in the liver, leads to DNA-adduct-forming intermediates that are detoxified further by additional steps in metabolism. Metabolizing genes that have been shown to activate or deactivate tobacco smoke constituents are: *CYP1A1*, *GSTM1*, *GSTT1*, *NAT2*, and *GSTP1*.²⁵⁶ Therefore, large studies have been undertaken to investigate the role of functional polymorphisms in these genes in lung cancer development.²⁵⁷ Also, as an extension of this approach, research is ongoing on the role of functional polymorphisms in DNA repair genes in the development of lung cancer.²⁵⁸ Furthermore, research is ongoing to determine whether the interaction of cigarette smoke with these genes increases the risk for lung cancer.²⁵⁹

Vegetable and Fruit Consumption

Although an inverse relationship between high levels of consumption of fruits and vegetables and the risk of lung cancer has been observed in both case-control and large cohort studies,²⁶⁰ a recent meta-analysis that included more than 3,000 incident cases of lung cancer in men and women, did not confirm these results.²⁴⁹ It is thought that this inverse relationship may have been due to counting an inverse association with one or a few foods as support for the benefit of fruits and vegetables, when this may have been the result of chance due to multiple comparisons. However, it is still possible that biologically active substances in fruits and vegetables do exist but in doses too small and not possible to estimate using food frequency questionnaires, and that measuring blood levels of candidate substances would be best for assessing these dietary exposures.²⁶¹

Physical Activity

A recent meta-analysis that evaluated the relationship between physical activity and lung cancer found that this was a statistically inverse relationship, in which several studies were able to adjust for smoking.²⁶² The ORs were 0.87 for moderate leisure-time physical activity and 0.70 for high physical activity, with the inverse association occurring for both sexes, although it was somewhat stronger for women. Four more recent prospective cohort studies, which all adjusted for smoking, yielded mixed results; with three out of the four studies showing an inverse relationship between physical activity and lung cancer risk.²⁶³⁻²⁶⁶ In the study that only included women (n= 36,929), physical activity was only inversely related to lung cancer risk in former and never smokers.²⁶⁶

Prostate Cancer

Prostate cancer is the most common and second deadliest cancer in US men.²⁶⁷ Clinical prostate cancer usually presents late in life, leaving much opportunity for preventive interventions. Although microscopic evidence of prostate cancer occurs in more than 70% of all men by age 70,²⁶⁸ the progression to clinically manifest cancer of the prostate is significantly more frequent in regions such as North America when compared to Asian countries.²⁶⁹ There is

also an increased incidence of clinical prostate cancer in Asian men who emigrate to the US compared to men that remain in Asian countries.^{270, 271} This feature of this disease suggests that environmental factors are contributors to the progression of prostate cancer. Preventive measures for this disease are not established, however, there is evidence that lifestyle modification that includes a diet rich in tomato products and controlling weight may reduce the risk for prostate cancer progression.

Diet

Several reports have noted an inverse association between a diet rich in tomato products and prostate cancer risk. The key component in tomatoes that is believed to be responsible for this effect is lycopene, which is a carotenoid and is the most effective antioxidant of all of the carotenoids.²⁷² As is the case with other micronutrients, most of the evidence for the protective effect of lycopene in humans is derived from observational studies. A recent review of the published epidemiological evidence suggested that there was a potential benefit of lycopene against the risk of prostate cancer, particularly the more aggressive forms of this cancer. Five of these studies supported a 30% to 40% reduction in this risk, and three were consistent with a 30% reduction in risk, but the results of these studies were not statistically significant, and seven were not supportive of an association between lycopene and prostate cancer risk.²⁷³ The largest dietary prospective cohort study that was conducted in male professionals, found that the consumption of 2-4 servings of tomato sauce per week was associated with nearly a 35% risk reduction of prostate cancer and a 50% reduction of advanced (extraprostatic) prostate cancer. Of the three blood-based prospective cohort studies, all demonstrated an inverse association between lycopene and prostate cancer risk, however, this association was only statistically significant related to aggressive prostate cancers. Thus, although not definitive, the data from these observational studies collectively suggests that lycopene may be protective for prostate cancer, particularly in the aggressive form.

Obesity and Overweight

In a recent meta-analysis that involved case-control and cohort studies, obesity was found to be positively associated with an increased risk of prostate cancer, particularly in the advanced stage tumors. In these studies the association was small, 5% on the average, across the categories for BMI, and the range of RR was 0.66-2.28. A similar risk was seen for height and prostate cancer incidence, but only among the cohort studies. There were also weak positive associations with height and waist circumference, but no notable relationship between WHR and the risk of prostate cancer. A methodological issue for many of the studies represented in this meta-analysis was recall bias due to study subjects recalling their height and weight.²⁷⁴ However, in a recent large prospective cohort study, BMI and adult weight gain was positively associated with prostate cancer mortality, with a RR of 2.12 for the highest BMI category ($\geq 35 \text{ kg/m}^2$).²⁷⁵

Despite the lack of an association between markers of obesity and prostate cancer from the above epidemiological studies, several biological markers that are related to obesity suggest an association of these markers with prostate cancer risk. Leptin, an adipocyte-derived hormone that regulates satiety and energy expenditure, has been shown to increase prostate cancer risk.²⁷⁶ In addition, higher serum insulin levels increase prostate cancer risk, independent of abdominal obesity.²⁷⁷ A meta-analysis of published studies on hormonal markers of prostate cancer risk also found that men with serum IGF-I levels in the upper quartile of the population distribution had a two-fold higher prostate cancer risk.²⁷⁸ However, how BMI

may play a role in the association of these markers with prostate cancer is complex and not well understood.

Summary and Conclusions

Although the underlying mechanisms that are operative in the association between lifestyle and the cancers presented in this review have not been established (Table 1), there is now overwhelming evidence that lifestyle factors affect breast, colorectal, lung, and likely prostate cancer risk. Physical activity, weight loss, and a reduction in alcohol use can strongly be recommended for the reduction of breast cancer risk. In addition, weight loss, physical activity, and the cessation of tobacco use are important behavior changes to reduce colorectal cancer risk, along with the potential benefit for the reduction of red meat consumption and the increase in folic acid intake. Smoking cessation is still the most important prevention intervention for reducing lung cancer risk, but recent evidence indicates that increasing physical activity may also be an important prevention intervention for this disease. The potential benefit of lifestyle change to reduce prostate cancer risk is growing with recent evidence indicating the importance of a diet rich in tomato-based foods and weight loss. Also, in the cancers for which there are established lifestyle risk factors, such as physical inactivity, obesity, and tobacco use for colorectal cancer, there is emerging information on the role that genetics plays in interacting with these factors, as well as the interaction of combinations of lifestyle factors. Integration of genetic information into lifestyle factors can help to clarify the causal relationships between lifestyle and genetic factors and assist in better identifying cancer risk, ultimately leading to better informed choices about effective methods to enhance health and prevent cancer.

Table 1. Biological Mechanisms that May be Involved in the Association of Lifestyle, Genes, and Cancer

Cancer	Possible Mechanisms
Breast	<p>Physical Activity Decreased circulating estrogen levels due to a decrease in SHBG levels. Prevents silencing of tumor suppressor genes, such as <i>APC</i>, in breast tissue due to gene promoter hypermethylation. Reduced production of IGF-I that promotes cancer cell growth, due to lower circulating levels of estrogen.</p> <p>Obesity and Overweight Aromatization of high levels of androgens in adipose tissue leading to higher circulating estrogen levels. Higher estrogen levels increase the production of insulin-like growth factors, such as IGF-I, which increases cancer cell growth.</p> <p>Alcohol Higher estrogen levels increase the production of insulin-like growth factors, such as IGF-I, which increases cancer cell growth. The combination of alcohol consumption and folate deficiency may alter folate metabolism that causes an imbalance in the DNA repair processes that promote cancer cell growth. Polymorphisms in the metabolizing genes for alcohol, <i>GSTM1</i> and <i>GSTT1</i>, in combination with alcohol consumption may promote cancer cell growth.</p>
Colorectal	<p>Physical Activity Increases bowel transit time, which may reduce mucosal exposure to fecal carcinogens. Decreases levels of insulin-like growth factors, such as IGF-I, which increases cancer cell growth. May prevent mutations of genes that regulate cell growth and apoptosis, such as <i>APC</i>, <i>p53</i>, and <i>Ki-ras</i>.</p> <p>Obesity and Overweight May increase levels of leptin and insulin-like growth factors, such as IGF-I, which increase cancer cell growth. Obesity produces a state of chronic inflammation that increases the production of free radicals that may lead to gene mutations that promote cancer cell growth. Obesity may cause mutations in genes involved in regulating cell growth and apoptosis, such as <i>Ki-ras</i>, which increases cancer cell growth.</p> <p>Folic Acid Deficiency Folic acid deficiency may alter gene expression through DNA methylation or by increasing the incorporation of uracil in DNA causing cancer cell growth.</p> <p>Tobacco Tobacco carcinogens in combination with specific polymorphisms of the metabolizing genes, <i>NAT2</i>, <i>CYP1A1</i>, <i>GSTM1</i>, and <i>GSTT1</i>, may increase the risk for initiating colorectal.</p>
Lung	<p>Tobacco Tobacco carcinogens initiate lung cancer by inducing gene mutations and genetic instability through the production of DNA-adducts. Specific polymorphisms of the genes that metabolize tobacco carcinogens, <i>NAT2</i>, <i>CYP1A1</i>, <i>GSTM1</i>, and <i>GSTT1</i>, may increase the risk for tobacco-induced lung cancer.</p>
Prostate	<p>Lycopene Lycopene may reduce the production of free radicals that may lead to gene mutations that promote cancer cell growth.</p> <p>Obesity and Overweight May increase levels of leptin, insulin, and insulin-like growth factors, such as IGF-I, which increase cancer cell growth.</p>

Abbreviations: SHBG, sex hormone-binding globulin; IGF-I, insulin-like growth factor.

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