Minireview

Prevention of Ovarian Cancer: Intraepithelial Neoplasia

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Abstract

To reduce the incidence and mortality associated with invasive cancers, the Intraepithelial Neoplasia (IEN) Task Force recommends that carcinogenesis be viewed as a disease that requires treatment. This publication outlines the current knowledge of IEN of the ovary and reviews chemoprevention possibilities for ovarian cancer. Ovarian cancer has the highest mortality of all of the gynecological cancers and is the fourth leading cause of death from cancer in women. The IEN Task Force has defined precancer as a noninvasive lesion that has genetic abnormalities, loss of cellular control functions, and some phenotypic characteristics of invasive cancer with a substantial likelihood of developing invasive cancer. The IEN Task Force recommends targeting moderate to severe dysplasia for new IEN treatment agents in clinical trials. Ovarian cancer does not have a clear preinvasive lesion yet merits considerable study for new prevention strategies because of the high mortality associated with ovarian cancer. There is a great unmet clinical need for treatments that can prevent ovarian cancer by providing nonsurgical options that treat the entire epithelial layer. New prevention strategies hold significant promise to reduce the mortality from ovarian cancer.

Introduction

Carcinogenesis must be viewed as a disease and disequilibrium that requires treatment to dramatically reduce the incidence and mortality associated with invasive cancers. The IEN[2]

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[2] The abbreviations used are: IEN, intraepithelial neoplasia; OSE, ovarian surface epithelial; EGFR, epidermal growth factor receptor; TGF,

Task Force has defined precancer as a noninvasive lesion that has genetic abnormalities, loss of cellular control functions, some phenotypic characteristics of invasive cancer, and predicts a substantial likelihood of developing invasive cancer. In demonstrating effectiveness and patient benefit of new IEN treatment agents in clinical trials, the IEN Task Force recommends targeting moderate to severe dysplasia, which is close in stage of progression to invasive cancer and thus substantially elevates the risk of developing cancer.

Epithelial ovarian cancer has the highest mortality rate of any of the gynecological cancers; the 5-year survival is no more than 30% despite aggressive treatment. Seventy percent of these cancers are diagnosed with widespread intra-abdominal disease or distant metastases, which partially accounts for the poor prognosis associated with ovarian cancer. Although up to 90% of stage IA tumors and 70% of stage II tumors can be cured by current management, the cure rate drops below 30% for Stage III and IV tumors. Even ovarian cancer limited to the pelvis has a 5-year survival of only 50% (1). This dismal overall prognosis for women with ovarian cancer results from an inability to detect ovarian cancers at an early, curable stage, from the lack of effective therapy for advanced disease, and from our incomplete understanding of both the early changes in the ovary that predate the development of cancer and the initiators of these changes. Although radical surgery, radiation therapy where appropriate, and new methods of chemotherapy have improved survival times, cure rates have stayed essentially the same over the last 20 years. Thus, early intervention with chemopreventive agents merits serious consideration as a desirable alternative to suboptimal treatment of invasive disease.

Cancer chemoprevention is a rapidly growing area of research because of the possibility to prevent disease and to restore cancer-suppressing cellular functions. Chemopreventives are micronutrients or medications that prevent or delay cancer in at-risk populations. Fundamental elements for chemoprevention studies include (*a*) a suitable cohort of patients with sufficient incidence to establish an acceptable risk:benefit ratio; (*b*) appropriate agents that are safe and whose use is supported by both epidemiological and mechanistic data; and (*c*) measurable biomarkers that are likely to be affected by the agent and whose modulation is predictive of the postulated chemopreventive activity (2). Biomarkers are important because they can be used in lieu of following patients prospectively until a cancer occurs, if they indicate a protective response to a chemopreventive agent. Several criteria must be met for biomarkers to be useful: (*a*) they are relevant to the development of neoplasia either phenotypically (proliferation, angiogenesis, or nuclear morphometry) or mechanistically (molecular markers); (*b*) they

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are modulated by chemopreventive agent; and (*c*) they should predict a decrease in carcinogenesis (3).

Epidemiology

High Epidemiological Risk. The etiology of ovarian cancer remains unknown; low prevalence rates, low participation rates, small sample sizes, and potential bias in the selection of control groups have limited the interpretation of results from epidemiological studies. However, multiple epidemiological studies agree that an increased risk of epithelial ovarian cancer has been linked to advancing age, family history of breast or ovarian cancer, and frequency of ovulation (4–15). Reproductive factors have been extensively studied, but interpreting these results has been complicated by the intercorrelation of reproductive characteristics (4–15). Despite these limitations, several factors related to ovulation have been consistently associated with increased or decreased risk of developing ovarian cancer. Risk is increased with uninterrupted ovulation (nulliparity), larger number of lifetime ovulatory cycles (early age at menarche and late age at menopause), and possibly hyperovulation (fertility drugs), whereas risk is reduced by factors that suppress ovulation [pregnancy, breast feeding, and OCP use (4–15)].

High-Risk Population

High Genetic Risk. Premenopausal women with a family history of breast and/or ovarian cancer constitute an important high-risk group and are excellent candidates for prevention strategies. Although only 10% of ovarian cancers are attributable to germ-line mutations, this high-risk population is an ideal patient population to target for preliminary chemoprevention studies because of the higher prevalence of ovarian cancer as compared with that seen in the general population. Women from a cohort of high-risk families carrying the BRCA1 mutation were observed to have an approximately 40–60% risk of developing ovarian cancer and an 85% chance of developing breast cancer (15). Multiple methods of calculating risk are available. The Parmigiani method (16) uses Bayes theorem and calculates likelihood ratios. The probability of a mutation in the general population is 0.04%–0.20%, with part of the variation attributable to the ethnic mix of the population. A family history of breast and/or ovarian cancer determines the risk calculation in a particular patient. High-risk family histories with an elevated risk of developing ovarian cancer include >2 breast cancers and 1 or more cases of ovarian cancer at any age, >3 cases of breast cancer before age 50 years, sister pairs with cancers less than age 50 years, cases of breast cancer occurring at or before age 40 years, Ashkenazi Jewish descent (which carries a 2% or greater risk of mutation; Ref. 17), or 1 or more cases of breast/ovarian cancer.

The ideal design for a chemoprevention trial includes a high-risk population with an identifiable and easily accessible preinvasive lesion (*e.g.,* IEN), a safe and effective chemopreventive agent, and surrogate end point biomarkers that have been validated as markers of regression of such lesions. For ovarian cancer chemoprevention trials, the targeted population should include high-risk women with a strong family history of breast/ovarian cancer, with or without a BRCA mutation, or with Ashkenazi Jewish descent. Although there is as yet no

identifiable preinvasive lesion of ovarian cancer (18), there is strong evidence for one based on the increased numbers of inclusion cysts and areas of proliferation noted in the ovaries of high-risk women seen in some studies (19); thus, this has the potential for use as a biomarker.

Pathology

IEN in the Ovary. We hypothesize that there is an IEN precursor to ovarian cancer; however, the natural history of ovarian cancer and the location of the ovary have made it difficult to characterize precursor lesions. The ovary is not routinely biopsied because of the inaccessibility of the ovary in its i.p. location and concern about the effect on fertility that might result from biopsy. Scully (20) has qualitatively described early histological changes in the ovary, whereas Deligdesch *et al.* (21, 22) have described them quantitatively with the use of nuclear texture analysis. These studies support the concept that ovarian cancer behaves in a similar manner to other epithelial cancers with an identifiable precursor. Other authors (23, 24) have described a pathological process in the ovary consistent with the IEN seen in other organ systems that occurred adjacent to existing cancers. Although progression from IEN to cancer has not yet been validated, there is accumulating evidence including a chain of underlying molecular events that supports the ovarian IEN concept.

The cell of origin of epithelial ovarian cancer remains controversial, although most investigators think it is the OSE cell. Many ovarian cancers are thought to arise from OSE cell-lined inclusion cysts (see Fig. 1); these small, subsurface cysts are hypothesized to arise from involution of ovarian surface epithelium at ovulation (20), but some inclusion cysts are thought to antecede ovulation because they are often present in fetal and juvenile ovaries (25). Small collections of malignant cells contiguous with normal ovarian epithelium suggestive of an IEN but not involving underlying tissues can be found in: (*a*) ovaries removed from women who eventually develop primary peritoneal carcinomatosis (19); (*b*) high-risk women who undergo prophylactic oophorectomy (19), particularly those with the BRCA1 mutations (24); and (*c*) in areas adjacent to stage I cancers that show a transition from malignant to normal epithelium (23, 24). However, a characteristic histological precursor lesion for ovarian cancer is not apparent in all prophylactic oophorectomy specimens (26–29). Whether these contradictory findings are due to differences in patient populations or differences in pathological techniques is not clear. However, these findings underscore the discrepancies present in our understanding of IEN of the ovary and suggest that the ovarian surface epithelium is probably the precursor for most epithelial ovarian cancers. OSE cells differ from peritoneal mesothelial cells because they overlie the ovarian stroma and are in close contact with the hormones secreted by the ovary. The chronic repair after ovulation and/or the influence of ovarian hormones are thought to increase the propensity of the OSE cells to undergo tumorigenesis and may account for the higher incidence of ovarian cancer compared with primary peritoneal cancer.

The molecular mechanisms leading to the initiation and progression of ovarian cancer remain elusive, partly because of the ovary's location and the consequent difficulty in identifying
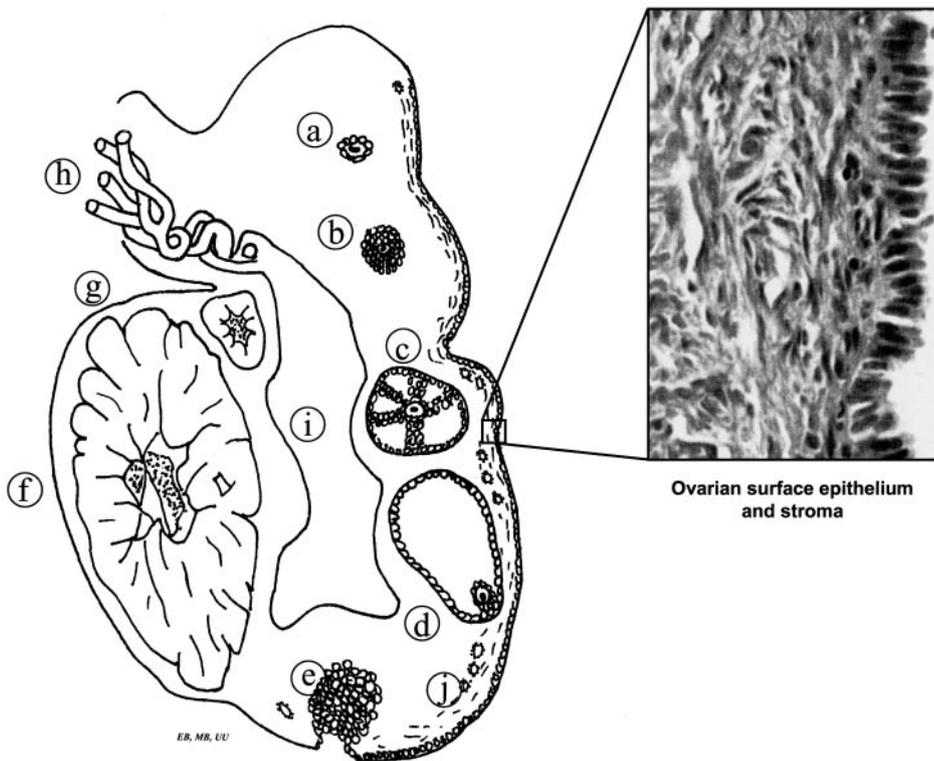
Ovarian surface epithelium and stroma

Fig. 1 Normal ovarian structures. *a*, primary follicle; *b*, secondary follicle; *c*, tertiary follicle; *d*, ovulatory follicle; *e*, hemorrhagic cyst; *f*, corpus luteum; *g*, corpus albicans; *h*, ovarian artery and vein; *i*, medulla; *j*, inclusion cyst.

early or precursor lesions. In contrast, analysis of colon, cervix, and head and neck cancers have resulted in a rapidly emerging understanding of the genetic events underlying the initiation and progression of these diseases and of the biological events that result from these genetic changes.

As with all cancers, ovarian cancer is a consequence of either germ-line or acquired somatic changes in genetic function. The acquired changes in gene expression or function can result from mutations or epigenetic alterations such as changes in methylation. Therefore, one important challenge is to link the genotypic changes that occur in ovarian cancer cells to the phenotypic and biological changes observed in human tumors and cell lines.

Although the association between ovulation and ovarian cancer is well accepted, little is known about the underlying biological mechanisms of this association. Ovulation is thought to be important for the development of inclusion cysts from which ovarian cancers may arise. In addition, ovulation, and particularly the high estrogen associated with ovulation, may provide a stimulus for proliferation of ovarian surface epithelium. Ovaries removed prophylactically from women with a strong family history of ovarian cancer demonstrate increased frequency of occult carcinomas, epithelial hyperplasia and atypia, and increased stromal activity (30). Epithelial hyperplasia and increased number of crypts (which are deep indentations of the ovary covered with surface epithelial cells) with an associated increase in proliferation may contribute to tumorigenesis by increasing the risk that a genetic alteration will occur.

OSE cells are generally quiescent but proliferate after ovulation to repair the defect created by the release of an oocyte from a mature follicle. Increased proliferation may contribute to the accumulation of genetic defects in the OSE cells. Furthermore, growth factors produced during wound healing may promote the survival of OSE cells with accumulated mutations. Alternatively, ovulation may be important for the development of inclusion cysts from which ovarian cancers may arise. Entrapment of ovarian epithelium in the stroma of the ovary may disrupt the normal relationship between the ovarian surface epithelium and the underlying stroma. Disruption of normal epithelial stromal interactions can increase mutation rates, directly contributing to ovarian cancer development. Furthermore, growth factors normally produced by the ovarian epithelium that would diffuse into the large potential space of the peritoneal cavity may be present at higher levels in the microenvironment of entrapped ovarian epithelium. Finally, ovarian epithelium in the stroma may be exposed to higher concentrations of paracrine growth factors produced by the stroma or to higher hormone levels than are present on the surface of the ovary. In support of the concept of increased ovulation conferring increased risk are the pathobiological data that show a strong correlation between the lifetime number of ovulations and the frequency of p53 mutations (19, 30). One biological hypothesis is that ovulation may result in genomic instability that occurs as a result of the repeated turnover of cells that renders cells sensitive to the high levels of gonadotropins or gonadotropin-releasing factors present postmenopausally.

Animal Models

A reliable animal model is invaluable in providing optimal flexibility for examining mechanistic, dose-response relationships and comparative efficacy. Ovarian chemoprevention studies of specific molecular targets could be accomplished with greater efficiency if an accepted rodent model of ovarian cancer were available. Under current circumstances, the opportunity to test the many hypotheses being generated by a growing list of potential agents with activity against targets implicated by the new molecular technologies is limited. Research to evaluate several candidate rodent models is being supported by the National Cancer Institute and its Mouse Consortium, and there has been investigation of both syngeneic models (31) by injecting malignant cells or by transfecting epithelial cells with oncogenes (32) to simulate development of a tumorigenic phenotype with variable success. In the meantime, the most widely accepted animal model for ovarian cancer prevention is the domestic white Leghorn chicken (33). Although investigators at The University of Texas M. D. Anderson Cancer Center (Houston, TX) are performing primate studies because of their close similarity to humans, the absence of tumor formation is a drawback, and little is known about primate ovarian carcinogenesis. The chicken, however, has an extremely high rate of Müllerian cancer, of which 30–50% are oviductal in origin. The spontaneous rate of ovarian cancers was approximately 19% in hens ranging from age 2–7 years (33). The potential utility of immunohistochemical markers in the chicken has been investigated to further develop the chicken (*Gallus domesticus*) as a model for spontaneous ovarian carcinoma. Antibodies used to characterize human tumors that were cross-reactive in chicken carcinomas included cytokeratin AE1/AE3, pan-cytokeratin, EGFR, HER-2, Lewis Y, carcinoembryonic antigen, TAG 72, proliferating cell nuclear antigen, p27, and TGF-α (34). Antibodies that were not cross-reactive included CA125, Ki67, Muc-1, and Muc-2. Oviductal cancers were not differentiated from ovarian cancers, which could limit the applicability of these markers. However, the white leghorn chicken model has considerable merit and is being investigated as a model for chemoprevention with the University of Illinois collaborating with Duke University.

Advantages of the chicken model include a high incidence of epithelial cancers. Disadvantages include a high incidence of oviductal cancers and lower correlation with humans than in primates. A study of progestin and 4-HPR in the chicken model is currently in progress. It will be interesting to see if marker modulation in this system corresponds to observations in humans and in cynomolgus macaques.

TKIs. Although the role of the EGFR family in ovarian carcinogenesis is not fully documented, it has been appreciated for some time that growth regulation and differentiation, in response to these receptors in normal ovarian surface epithelium, follow a complex system of interactions that are tissue specific. EGFR, along with the other three members of this receptor family (HER-2, HER-3, and HER-4), is detected immunohistochemically in normal OSE cells at low or moderate intensity (35, 36). Under normal conditions, epidermal growth factor, TGF-α, and amphiregulin provide growth-stimulatory signals to EGFR, and growth inhibition is mediated by TGF-β autocrine feedback (36).

Expression of the various EGFRs in ovarian cancer has been studied extensively by immunohistochemistry. Abnormal expression implying abnormal signaling through EGFR pathways is a common finding in ovarian malignancy. In contrast to the levels observed in normal ovarian surface epithelium, EGFR may be overexpressed in 50–70% of ovarian cancers (37–40). HER-2 is intensely expressed in approximately 10–20% of ovarian cancers and moderately expressed in another 20–40% more cases (41). Because of heterodimer formation among EGFR family members, multiplex expression of certain receptors may be of particular biological relevance. For instance, coexpression of EGFR and HER-2 has been reported in 30–50% of some case series (38, 39). Although intense expression of EGFR and HER-2 is not seen in normal cells and appears to confer a negative prognosis in malignancy, conflicting results regarding prognostic implications are found in the literature. This confusion should resolve as the understanding of EGFR dysregulation in ovarian cancer is updated. For instance, EGFR overexpression is reported to be associated with serous histology (40), and amphiregulin expression is reported to be associated with mucinous histology (42). These observations suggest that histological heterogeneity of ovarian cancer may contribute to the complexity of interpreting the results of growth factor pathway analysis.

A model of the expression patterns underlying EGFR dysregulation has been developed on the basis of EGFR-mediated signals in human ovarian cancer cell lines (43). In brief, the major observation is that coexpression of EGFR and HER-2 facilitates transactivation by epidermal growth factor and produces a strong mitogenic signal. Coexpression of *Her-2* gene product and EGFR was present in 68% of ovarian cancers (44). Two other observations include: (*a*) heregulin activates HER-4, either on its own or with HER-3; and (*b*) HER-3 and HER-4 do not cross-react with EGFR and HER-2 after stimulation with heregulin. Activation of the EGFR and HER-2 heterodimer may be the predominant growth-stimulatory signal in ovarian epithelium, as suggested by the commonly observed overexpression of these two receptors in ovarian cancer (45). If unattenuated, it is plausible that this signal could be a critical driving force in ovarian carcinogenesis. This hypothesis is the basis for testing the potential usefulness of TKIs for preventing the abnormal proliferation of ovarian epithelium that is postulated to precede malignant transformation (see "New Agents").

COX-2 Expression. Abnormal COX-2 expression is found in ovarian cancer. Matsumoto *et al.* (46) have reported a series of 28 ovarian carcinomas, of which 79% were positive for COX-2 expression overall, with 61% strongly positive and 18% weakly positive. In contrast, COX-2 expression was not found in the surface epithelium or inclusion cysts of the uninvolved ovaries in this series (46). In these samples, COX-2 expression was correlated with vascular endothelial growth factor expression. Ovarian cancer cell lines that express COX-2 include SKOV3, CAOV3, and OVCAR3, all of which undergo growth suppression by a COX-2 inhibitor *in vitro* (47).

PI3K. PI3K represents a node in a pathway downstream to the proliferation signals originating from the EGFR family. The potential importance of PI3K in the malignant process is

suggested by its position in signal transduction between EGFR and AKT2, which has been identified as another site of oncogene abnormality in ovarian cancer (48). PI3K has become a focus of attention because amplification of PI3K activity is observed in approximately 40% of ovarian tumors confined to the subset of tumors with serous histology (49, 50). PTEN mutations predominate in endometrioid ovarian cancers. In addition to increased proliferation, decreased apoptosis is also found in association with increased PI3K activity (51). Amplification of PI3K activity is observed in several ovarian cancer cell lines, including OVCAR3. Mechanistic studies have shown that enzyme activity of PI3K is reduced more than 80% by specific inhibitor LY294002 (52). LY294002 causes a dose-dependent reduction in growth of OVCAR3 cells in culture and reduces tumor burden in nude mice inoculated with OVCAR3 (52).

Agents

Well-known agents are being considered for use in reducing the risk of developing ovarian cancer. One of these is the OCP. The OCP reduces the risk of developing ovarian cancer with odds ratios ranging from 0.25 to 0.8 (12–14, 53–55). Its protective effect is independent of study design (case-control or cohort study) and study population (population based or hospital based). The reduction in risk appears to persist for up to 10 or more years after discontinuation of OCP. Based on epidemiological findings and assuming a lifetime protective effect and similar protection by all formulations of OCP, it is estimated that more than half of all ovarian cancers in the United States could be prevented by the use of OCP for at least 4 years (53, 54). A recent case control study (56) that compared high-dose OCP with mid-dose OCP showed greater protection from the high-dose OCP. Both progestin and estrogen concentrations are higher in the high-dose pill, but the greater protective effect is attributed to the progestin component. There have not been studies comparing the mid-dose pill with the low-dose pill, but it would be important to determine the effectiveness of the low-dose pill. In monkey studies using both progestins and OCP (57), the progestin arm had more apoptosis of the OSE cells than the OCP arm, suggesting that progestin may be the active component in the OCP, although variances were large, and median values were used because of the large variability. A reanalysis of the data from the cancer and steroid hormone study (58), which examined the strength of OCP components taken by 390 women diagnosed with ovarian cancer compared with controls, found the greatest reduction in ovarian cancer risk associated with the highest progestin potency. In addition to this information, a recent report has explored the relationship between progestin, TGF-β expression, and apoptosis in the ovarian epithelium of cynomolgus macaques. Exposure to progestin changed the expression of TGF-β, lowering TGFβ-1 with a corresponding increase in TGF-β2/3, correlating closely with induction of substantial apoptosis in the ovarian epithelium (59). Consequently, the progesterone receptor is a prime candidate as a preventive target. Definitive mechanistic and clinically based studies are of great importance in refining the opportunity to specify a role for progestins, agent/dose/schedule, in ovarian cancer risk management. This body of evidence makes the OCP

(and potentially the progestin component) an excellent candidate chemopreventive agent for ovarian cancer, although more needs to be learned about the mechanism of its protective effect.

Use of the OCP for 5 years decreases the risk of ovarian cancer by 50% (53–55) but reduces the number of ovulatory cycles by approximately 15 percent. Consequently, there is not a linear correlation between the duration of OCP use and the impact on ovarian oncogenesis, suggesting that more complex mechanisms other than just ovulation suppression may be at work in the chemopreventive activity of OCP. Inhibition of gonadotropin release from the pituitary, one of the effects of OCP use, or other unknown effects of estrogens and progestins may also play a role in this chemopreventive activity.

Retinoids.   As with OCP, the antineoplastic effect of 4-HPR is not completely understood. In the laboratory, the activity of retinoids in ovarian cancer has been studied in various ways. In four different ovarian cancer cell lines, 4-HPR was the most effective at suppressing growth compared with all-*trans*-RA, 9-*cis*-RA, and 13-*cis*-RA (60). Studied in more detail in cell line OVCAR3, 4-HPR was found to weakly activate only RARγ, with induction of apoptosis appearing to occur independent of retinoid receptors. This result is consistent with the classification of 4-HPR as a receptor-independent apoptotic retinoid. In addition to retinoid receptors, several other targets have been suggested to mediate their effect. They include the destruction of the mitochondrial membrane by reactive oxygen species and stabilization of the Rb2/p120 protein that mediates retinoid induced growth arrest (61).

Epidemiological and laboratory data suggest that retinoids may have a role as preventive or therapeutic agents for ovarian cancer (58, 62, 63). Fenretinide or 4-HPR has few side effects compared with other vitamin A derivatives and is currently being used in chemoprevention studies of other organ sites, including lung, head and neck, cervix, and bladder. Experimental studies have demonstrated that retinoids can affect human ovarian cancer cell growth by inhibiting proliferation and inducing apoptosis (58, 62); preliminary data from our laboratory show that 4-HPR induces apoptosis in immortalized OSE cells and in normal OSE cells (64). Some cells respond to 2 μM/ml 4-HPR, which might be achievable by oral administration, but others require as high as 10 μM/ml to have an effect. The 10 μM/ml dose would not be achievable by an oral dose because of side effects, particularly skin and ophthalmic effects (nyctaglia). Because epithelial ovarian cancer is thought to arise from a neoplastic process that results from a series of mutations in the OSE cells, the probability of developing a neoplasm would decrease if premalignant or genetically altered cells were eliminated by apoptosis.

In Italy, a randomized trial for the prevention of breast cancer has provided preliminary evidence that retinoids, specifically 4-HPR, may prevent or delay the development of ovarian cancer (63). After surgical treatment for breast cancer, 2972 patients were assigned to treatment with 4-HPR (1422) or placebo (1427) to prevent development of new primary breast cancers. After a median follow-up of 51.9 months, no overall difference in the development of new primary breast cancers was evident; however, there was a significant difference in the numbers of ovarian cancers that developed. During the treatment period, six new cases of ovarian cancer were diagnosed in

the placebo group *versus* none in the 4-HPR group ($P =$ 0.0162). After cessation of treatment, there were four additional cancers in the control group and six in the 4-HPR group, suggesting that the effect was not durable. There was also a difference in the characteristics between groups: the control group was more likely to have a BRCA mutation than the 4-HPR group, which suggests that the difference may be due to the BRCA status rather than drug effect (65). However, when combined with the cell work, there is the suggestion that retinoids may have chemopreventive activity in the ovary but may need to be administered for long periods of time or to have a different dosing developed so that higher doeses could be achieved without toxicity.

Some low-toxicity retinoids, known as heteroarotinoids, share the receptor-independent apoptotic profile of 4-HPR and may be candidates for development as chemopreventive agents (61). In addition to this group of retinoids, AHPN/CD437, a conformationally restricted retinoid engineered to bind selectively to RARγ, also shares the apoptotic profile of 4-HPR. In ovarian tumor cell cultures, exposure to AHPN was associated with increased expression of *BAX* and decreased expression of *Bcl*-2 (66, 67). Agent development for ovarian risk reduction will benefit from mechanistic studies of apoptotic induction by 4-HPR and functionally similar compounds such as AHPN. Retinoids that suppress both growth and survival of abnormal cells hold more promise as chemopreventive agents. Prioritizing retinoids for ovarian cancer prevention will ultimately depend on the overall interrelationship among antiproliferative, differentiating, and apoptotic properties of these compounds.

Although there are still too little data to definitively guide chemopreventive studies, there is compelling evidence that as many as 50% of ovarian cancers may be prevented with OCP, and possibly even more may be prevented if a combination of the active ingredients (presumably progesterone) and a vitamin A derivative could be combined for use in high-risk women. Likewise, a similar reduction might be obtained if the active component of OCP could be administered to low-risk women, the group that develops 90% of the ovarian cancers.

Biomarkers

Biomarkers need to be identified that are predictive of drug or micronutrient activity and pharmacodynamics because the modulation and utility of particular biomarkers will depend on the drug-specific mechanism of action and conditions of use for any given agent. At the current time, little is known about effective biomarkers for drug activity in ovarian cancer chemoprevention. Markers of proliferation and apoptosis are key biomarkers in prevention. Apoptosis is hypothesized to be one of the major mechanisms by which cells with genetic alterations are eliminated (68). In a pivotal trial, primates were treated for 2 years with OCP, estrogen, progestin, or placebo (69). After this period, ovaries were removed, and their surface epithelia were assessed for apoptosis. OCP and progestin significantly increased apoptosis in OSE cells from 5% (baseline) to 25%, whereas estrogen had no effect. If OCP increased the rate of apoptosis in epithelial cells from human ovaries, as they have been found to do in primate ovaries, apoptotic elimination of aberrant cells might be one of the mechanisms underlying the

chemopreventive effects of OCP. In the primate, the high rate of apoptosis (25%) also indicates that either a very large proportion of OSE cells had underlying genetic abnormalities or a number of NOE cells underwent apoptosis in response to components of the OCP. This 25% frequency of apoptosis in the primates appears particularly high when it is considered that it represents a "snapshot" in time and that many cells may already have undergone apoptosis and been cleared from the system. One possible explanation may be the use of a Triphasil pill that has the highest concentration of the progestin in the third week. These monkeys were sacrificed in the third week of their OCP use.

In cell culture, different retinoids (including 4-HPR and all-*trans*-RA) inhibit proliferation and induce apoptosis in a number of tumor cell types [including ovarian cancer cell lines (57, 70–74)]. In at least some cell lineages, 4-HPR is more effective than other retinoids at inducing apoptosis (57) and can induce apoptosis in cells resistant to conventional retinoids. However, the mechanism by which 4-HPR and other retinoids induce growth inhibition and apoptosis is unclear. Most, but not all, studies indicate a correlation between RARβ expression or the ability to induce its expression and the ability of 4-HPR to induce growth inhibition and apoptosis (70–72). However, in ovarian cancer cells, 4-HPR effect appears to be receptor independent (61). Induction of reactive oxygen species is another proposed mechanism (74) of 4-HPR, but there are no data available on OSE cells or ovarian cancer cells. These biomarkers of retinoid activity warrant further exploration.

Growth Factor Specific. TGF-β is another potential biomarker of chemoprevention. It can induce growth arrest and apoptosis of ovarian cancer cell lines, as well as ovarian cancer cells isolated directly from patients (73, 74). In several cell types, including ovarian stroma, steroid hormones can increase TGF-β production and activation (75–79). Whether TGF-β, in concert with retinoids or steroids, induces apoptosis in ovarian epithelial cells *in vitro* or, more importantly, *in vivo* remains to be assessed. A recent histochemical evaluation of the primate ovary from primates receiving either progestin alone or the Triphasil OCP found an increase in expression of TGF-β2, but not TGF-β1, suggesting that TGF-β2 may be modulated by OCP, serving as a marker of progestin activity (59). Thus, TGF-β and its receptors definitely merit exploration. Other potential biomarkers include proliferative markers, such as Ki67, which are currently being used to evaluate the antiproliferative effects of progesterone.

Stromal cells may play an important role in epithelial carcinogenesis. Both types of cells contribute to the extracellular matrix (80), and stromal cells may influence some of the premalignant changes that occur in the epithelial cells (81). Epithelial ovarian cells express both cytokeratin and vimentin, suggesting a dual phenotype consistent with a multipotential stem cell origin. These epithelial cells produce both epithelial and mesenchymal components of extracellular matrix in tissue culture, which is consistent with their dual phenotype (80). KGF, a mesenchymal growth factor that mediates epithelial-stromal interaction, has been recently studied as a factor in early carcinogenesis (82). Fresh NOE cells, but not stromal cells, were found to highly express KGF, which subsequently growth-stimulated NOE cells in an autocrine manner (83). HGF and its

receptor, Met, have also been studied. HGF and KGF, as well as Kit ligand, have been found to interact and promote NOE cell growth and growth factor expression, suggesting that these may play a role in the growth stimulation that accompanies the carcinogenic process (84). Wong *et al.* (85) found that NOE cells from women without a family history of ovarian cancer down-regulated the HGF receptor with increasing passage, whereas the NOE cells from women with a family history of ovarian cancer did not, suggesting that HGF may be a growth regulator, particularly in cells destined to develop cancers (85). Telomerase may be an additional marker warranting both study and targeting. These biomarkers need further study to understand their role in modulating growth and to determine which growth modulators might be a target for prevention.

Optical Spectroscopy

One of the more exciting prospects for an early marker of ovarian cancer is optical spectroscopic signatures. In the last decade, substantial research has lead to useful optical methods of diagnosing early cancers (86–92). Fluorescence spectroscopy is being used to detect cancers noninvasively in many organ systems using a probe that can interrogate the tissue. The system utilizes redox potential (ratio), which is calculated by (FAD/ (FAD + NADH) and is, in part, a measure of the relative hypoxia of the tissue (93). FAD and NAD(P) are reduced in the citric acid cycle (anaerobic glycolysis) to FADH and NAD(P)H, which are used as coenzymes in the electron transport chain. In tumors, these coenzymes will accumulate in their reduced states (NADH and FADH) and produce a unique fluorescence signature (NADH high, FAD low) as a result of alterations in blood flow, decreases in tissue pH, and abnormalities in mitochondria and in transport of electron carrier molecules into the mitochondria (93, 94), where the electron transport chain functions. In a pilot study (95), patterns of fluorescence called excitation/emission matrices differed between normal ovaries and areas of invasive cancer and thus are promising for early detection of ovarian cancer. As anticipated, redox potentials were 50% lower in the cancer than in the normal ovary with peaks at 350 nm (excitation) and 460 nm (emission), representing both collagen and NADH. Even more exciting, however, was our recent primate study of fluorescence spectroscopy as a marker for drug activity in the ovary (96). Unlike cancer, where redox potentials are reduced, redox potentials were increased in response to both OCP and 4-HPR. Changes in fluorescence signatures were hypothesized to be due to a decrease in NAD(P)H and an increase in FAD in response to the drugs. 4-HPR had the least effect on the fluorescence signature of NAD(P)H and the greatest effect on the area corresponding to FAD, in contrast to OCP, suggesting that each agent has a unique effect on cellular metabolism. These agents also produced an increase in the redox-related potential of the target organ, suggesting that hypoxia was less extensive and that the system was more quiescent. Thus, optical spectroscopic signatures may serve as an early marker of drug activity.

Cell culture data (97) show that retinoids can induce apoptosis or inhibit growth in both normal and immortalized OSE cells. Cell studies measuring fluorescence emission compared with percentage of apoptosis and growth inhibition showed that both apoptosis and growth inhibition correlated with redox ratio ($P = 0.0274$), FAD fluorescence intensity correlated with apoptosis ($P < 0.001$), and NAD(P)H fluorescence intensity correlated with cell survival ($P = 0.04$; Ref. 68).

New Agents

Given the preponderance of evidence that OCP and/or retinoids have a role to play in ovarian cancer prevention, an initial consideration for the development of new agents would be optimizing the effect of these two categories of agents on ovarian cancer risk reduction. In general, recent progress in pharmacological intervention has been achieved by identifying a specific target that is critical to a pathological process. Disruption of a critical pathological signal by eliminating target function can be the key to disease prevention as well as disease control. Evidence reviewed above suggests that OCPs disrupt a critical pathway in early ovarian carcinogenesis in a substantial proportion of women at risk, but a specific target has not been clearly identified. A recent study supports the theory that the progesterone component of OCPs is responsible for reducing ovarian cancer risk.

In addition to the targets suggested by the observation of ovarian cancer risk reduction associated with the use of OCP or 4-HPR, the molecular analysis of malignant ovarian tumors has identified other candidate prevention targets. Selected oncogenes, growth factors, and signal transduction pathways are connected with ovarian carcinogenesis. The focus on targets related to the EGFR family, P13K, and COX2 is guided not only by preclinical studies but also by the presumption that relatively nontoxic oral agents in these categories are either available or about to become available.

TKIs. TKIs are of interest to ovarian cancer prevention because of their effect on the activation of EGFRs. In general, the dose-limiting toxicities for TKIs are skin rash and/or diarrhea. In the prevention setting, it may be possible to identify conditions of use that will avoid these toxicities. Alternatively, if preclinical concepts of prevention are demonstrated with compounds like these, it may be possible to identify less toxic versions of these agents that reduce cancer risk. Beyond EGFR-selective agents, there are TKIs in development with a different range of activity. For instance, CI-1033 is a potent inhibitor of kinase activity across the entire EGFR family. Agents selective for HER-2 are also in development.

Examples of TKIs that are of theoretical interest for testing in ovarian cancer prevention studies are ZD1839 (Iressa), OSI774, and PKI-166 (98, 99). As a pyrolopyrimidine, PKI-166 is structurally different, but like ZD1839 and OSI774, targets EGFR. All of these agents have been used in clinical trials and could be studied in model systems to generate preclinical data relevant to ovarian cancer prevention. EGFR, HER-2, and HER-4 all have a tyrosine kinase domain that can be activated when particular EGFR dimer-ligand complexes are formed. As members of a structural class of compounds known as quinazolines, ZD1839 and OSI774 are structurally similar and selectively deactivate the tyrosine kinase of EGFR. These agents might be particularly useful if it could be demonstrated that an EGFR-selective drug deactivates abnormal EGFR/HER-2 heterodimer expression in ovarian epithelium. In breast cancer cells

that overexpress HER-2, blocking transmodulation through EGFR with an EGFR-specific TKI is known to halt growth (100).

PI3K Inhibition. Because of the position downstream to the proliferation signals originating from the EGFR family, agents targeting PI3K might have chemopreventive activity on the basis of an antiproliferative effect. P13K inhibitors have not reached clinical trials, so future use of agents in this class for chemoprevention awaits their further pharmacological development.

COX-2 Inhibition. Another target of chemopreventive interest is COX-2 (101). COX-2 is an inducible enzyme of inflammation, mediating the conversion of arachidonic acid to prostaglandins. Attention has been called to the role that inflammation might play in ovarian carcinogenesis (102). It remains to be seen whether COX-2 inhibitors can be used to modulate COX-2 expression in ovarian epithelium and whether such modulation has a role early in carcinogenesis. As with the other agents mentioned in this review, it would be helpful to have a valid animal model of ovarian carcinogenesis to use in the development of preclinical data.

Clinical Trials

There are currently ongoing trials of both high low- and high-risk women for investigating chemopreventive agents in the ovary. Fox Chase Cancer Center has a trial using 4-HPR in high-risk women undergoing oophorectomy. The University of Texas M. D. Anderson Cancer Center and the University of Arizona have chemoprevention trials in both low- and high-risk women using OCPs and 4-HPR alone and in combination for women undergoing oophorectomy. This is early exploratory work, and findings from these trials will serve as templates for additional trials. Markers that are elucidated as a result of these trials will help determine which are the best biomarkers for drug activity. Following the results of these and other trials that may be starting in the next decade, larger randomized prospective trials will be important to determine the true preventive activity of these and other agents.

Discussion

Of the four criteria given in the opening definition of IEN, the most difficult to pinpoint in ovarian cancer is the abnormal phenotype. Although access to early ovarian neoplasia is limited by anatomical circumstance, there may, in fact, be biological reasons why an understanding of ovarian IEN is elusive. Ovarian cancer has been described as diseases (37), and, in fact, more than 40 histological entities contribute to the WHO classification of epithelial tumor types. Heterogeneity in ovarian cancer histology suggests a corresponding complexity in IEN. Also, it is recognized that malignant cells with a specific and identifying molecular fingerprint are not always histologically unidentifiable in seemingly normal epithelium adjacent to tumor (34). Given these observations, it may ultimately be necessary to rely on the genetic and consequent functional abnormalities to identify the precursor population of cells that gives rise to invasive ovarian cancer. In addition to the spectroscopic technique described above, genomic and proteomic methods are now being developed that may facilitate the definition of localized precur-

sors of ovarian cancer (103). The possibility of analyzing proteins characteristic of cancer risk and shed from ovarian IEN into serum (104–107) appears to offer an attractive alternative to the direct assessment of the ovarian epithelium by microlaparotomy for examination by spectroscopy or biopsy and subsequent microdissection.

References

1. Hoskins, W. J. Prospective on ovarian cancer: why prevent? J. Cell. Biochem. Suppl., *23:* 189–199, 1995.

2. Kelloff, G. J., Boone, C. W., Crowell, J. A., Nayfield, S. G., Hawk, E., Steele, V. E., Lubet, R. A., and Sigman, C. C. Strategies for Phase II cancer chemoprevention trials: cervix, endometrium, and ovary. J. Cell. Biochem. Suppl., *23:* 1–9, 1995.

3. Dhingra, K. A Phase II chemoprevention trial design to identify surrogate endpoint biomarkers in breast cancer. J. Cell. Biochem. Suppl., *23:* 19–24, 1995.

4. Casagrande, J. T., Pike, M. C., Ross, R. K., Louise, E. W., Roy, S., and Henderson, B. E. Incessant ovulation and ovarian cancer. Lancet, *2:* 170–172, 1979.

5. Greene, M. H., Clark, J. W., and Blayney, D. W. The epidemiology of ovarian cancer. Semin. Oncol., *11:* 209–226, 1984.

6. Hartge, P., Schiffman, M. H., Hoover, R., McGowan, L., Lesher, L., and Norris, H. J. A case-control study of epithelial ovarian cancer. Am. J. Obstet. Gynecol., *161:* 10–16, 1989.

7. Hildreth, N. G., Kelsey, J. L., LiVolsi, V. A., Fischer, D. B., Holford, T. R., Mostow, E. D., Schwartz, P. E., and White, C. An epidemiologic study of epithelial carcinoma of the ovary. Am. J. Epidemiol., *114:* 398–405, 1981.

8. Joly, J. D., Lilienfeld, A. M., Diamond, E. L., and Borss, I. D. J. An epidemiologic study of the relationship of reproductive experience to cancer of the ovary. Am. J. Epidemiol., *99:* 190–209, 1974.

9. Kvale, G., Heuch, I., Nilssen, S., and Beral, V. Reproductive factors and risk of ovarian cancer. A prospective study. Int. J. Cancer, *42:* 246–251, 1988.

10. Mori, M., Harabuchi, I., Miyake, H., Casagrande, J. T., Henderson, B. E., and Ross, R. K. Reproductive, genetic, and dietary risk factors for ovarian cancer. Am. J. Epidemiol., *128:* 771–777, 1988.

11. Whittemore, A. S., Harris, R., and Itnyre, J. Collaborative Ovarian Cancer Group. Characteristics relating to ovarian cancer risk: collaborative analysis of 12 U.S. case-control studies. II. Invasive epithelial ovarian cancers in white women. Am. J. Epidemiol., *136:* 1184–1203, 1992.

12. Franceschi, S., Parazzini, F., Negri, E., Booth, M., La Vecchia, C., Beral, V., Tzonou, A., and Trichopoulos, D. Pooled analysis of 3 European case-control studies of epithelial ovarian cancers. III. Oral contraceptive use. Int. J. Cancer, *49:* 61–65, 1991.

13. Centers for Disease Control Cancer and Steroid Hormone Study. Oral contraceptive use and the risk of ovarian cancer. J. Am. Med. Assoc., *249:* 1596–1599, 1983.

14. Rosenberg, L., Shapiro, S., Slone, D., Kaufman, D. W., Helmrich, S. P., Miettinen, O. S., Stolley, P. D., Rosenshein, M. B., Schottenfeld, D., and Engle, R. L., Jr. Epithelial ovarian cancer and combination oral contraceptives. J. Am. Med. Assoc., *247:* 3210–3212, 1982.

15. Easton, D. F., Ford, D., and Bishop, D. T. Breast and ovarian cancer incidence in BRCA-1 mutation carriers. Breast Cancer Linkage Consortium. Am. J. Hum. Genet., *56:* 265–271, 1995.

16. Berry, D., Parmigiani, G., Sanchez, J., Schildkraut, J., and Winer, E. Probability of carrying a mutation of breast-ovarian cancer gene BRCA-1 based on family history. J. Natl. Cancer Inst. (Bethesda), *89:* 227–238, 1997.

17. Struewing, J., Hartge, P., Wacholder, S., Baker, S., Berlin, M., McAdams, M., Timmerman, M., Brody, L., and Tucker, M. The risk of cancer associated with specific mutations of BRCA1 and BRCA2 among Ashkenazi Jews. N. Engl. J. Med., *336:* 1401–1408, 1997.

18. Gershenson, D. M., Tortolero-Luna, G., Malpica, A., Baker, V. V., Whittaker, L., Johnson, E., and Mitchell, M. F. Ovarian intraepithelial neoplasia and ovarian cancer. Obstet. Gynecol. Clin. N. Am., *23:* 475–543, 1996.

19. Salazar, H., Godwin, A. K., Daly, M. B., Laub, P. B., Hogan, W. M., Rosenblum, N., Boente, M. P., Lynch, H. T., and Hamilton, T. C. Microscopic benign and invasive malignant neoplasms and a cancer-prone phenotype in prophylactic oophorectomies. J. Natl. Cancer Inst. (Bethesda), *88:* 1810–1820, 1996.

20. Scully, R. E. Pathology of ovarian cancer precursors. J. Cell. Biochem. Suppl., *23:* 208–218, 1995.

21. Deligdisch, L., Miranda, C., Barba, J., and Gil, J. Ovarian dysplasia: nuclear texture analysis. Cancer (Phila.), *72:* 3253–3257, 1993.

22. Deligdisch, L., Gil, J., Kerner, K., Wu, H. S., Beck, D., and Gershoni-Baruch, R. Ovarian dysplasia in prophylactic oophorectomy specimens, cytogenetic and morphometric correlations. Cancer (Phila.), *86:* 1544–1550, 1999.

23. Puls, L., Powell, D., DePriest, P. D., Gallion, H. H., Hunter, J. E., Kryscio, R. J., and van Nagell, J. R., Jr. Transition from benign to malignant epithelium in mucinous and serous ovarian cystadeno-carcinoma. Gynecol. Oncol., *47:* 53–57, 1992.

24. Plaxe, S. C., Deligdisch, L., Dottino, P. R., and Cohen, C. J. Ovarian intraepithelial neoplasia demonstrated in patients with stage I ovarian carcinoma. Gynecol. Oncol., *38:* 367–372, 1990.

25. Blaustein, A. Surface cells and inclusion cysts in fetal ovaries. Gynecol. Oncol., *12:* 222–233, 1981.

26. Blaustein, A., Kantius, M., Kaganowicz, A., Pervez, N., and Well, J. Inclusions in ovaries of females aged day 1–30 years. Int. J. Gynecol. Pathol., *1:* 145–153, 1982.

27. Lu, K., Garber, J., Cramer, D., Welch, W., Niloff, J., Schrag, D., Berkowitz, R., and Muto, M. Occult ovarian tumors in women with BRCA1 or BRCA2 mutations undergoing prophylactic oophorectomy. J. Clin. Oncol., *18:* 2728–2732, 2000.

28. Stratton, J. F., Buckley, C. H., Lowe, D., Ponder, B. A. J., and UKCCCR Familial Ovarian Cancer Study Group. Comparison of prophylactic oophorectomy specimens from carriers and non-carriers of a *BRCA1* or *BRCA2* gene mutation. J. Natl. Cancer Inst. (Bethesda), *91:* 626–628, 1999.

29. Barakat, R. R., Federici, M. G., Saigo, P. E., Robson, M. E., Offit, K., and Boyd, J. Absence of premalignant histologic, molecular or cell biologic alterations in prophylactic oophorectomy specimens from BRCA1 heterozygotes. Cancer (Phila.), *89:* 383–390, 2000.

30. Casey, M. J., Bewtra, C., Hoehne, B. S., Tatpati, A. D., Lynch, H. T., and Watson, P. Histology of prophylactically removed ovaries from BRCA1 and BRCA2 mutation carriers compared with non-carriers in hereditary breast ovarian cancer syndrome kindreds. Gynecol. Oncol., *78:* 278–287, 2000.

31. Roby, K. E., Taylor, C. C., Sweetwood, J. P., Cheng, Y., Pace, J. L., Tawfik, O., Persons, D. L., Smith, P. G., and Terranova, P. E. Development of a syngeneic mouse model for events related to ovarian cancer. Carcinogenesis (Lond.), *21:* 585–591, 2000.

32. Davies, B. R., Auersperg, N., Worsley, S. D., and Ponder, B. A. J. Transfection of rat ovarian surface epithelium with *erb*-B2/*neu* induces transformed phenotypes *in vitro* and the tumorigenic phenotype *in vivo*. Am. J. Pathol., *152:* 297–306, 1998.

33. Fredrickson, T. N. Ovarian tumors of the hen. Environ. Health Perspect., *73:* 35–51, 1987.

34. Rodriguez-Burford, C., Barnes, M. N., Berry, W., Partridge, E. E., and Grizzle, W. E. Immuno-histochemical expression of molecular markers in an avian model: a potential model for preclinical evaluation of agents for ovarian cancer chemoprevention. Gynecol. Oncol., *81:* 373–379, 2001.

35. Berchuck, A., Rodriguez, G. C., Kamel, A., Dodge, R. K., Soper, J. T., Clarke-Pearson, D. L., and Bast, R. C., Jr. Epidermal growth factor receptor expression in normal ovarian epithelium and ovarian cancer. I. Correlation of receptor expression with prognostic factors in patients with ovarian cancer. Am. J. Obstet. Gynecol., *164:* 669–674, 1991.

36. Berchuck, A., Kamel, A., Kerns, W. B., Kinney, R., Soper, R., Dodge, D. L., Clarke-Pearson, P., McKenzie, S., Yin, S., and Bast, R. C., Jr. Overexpression of HER-2/neu is associated with poor survival in advanced epithelial ovarian cancer. Cancer Res., *50:* 4087–4091, 1990.

37. Auersperg, N., Edelson, M. I., Mok, S. C., Johnson, S. W., and Hamilton, T. C. The biology of ovarian cancer. Semin. Oncol., *25:* 281–304, 1998.

38. Henzen-Logmans, A. C., van der Burg, M. E. L., Foekens, J. A., Berns, P. M. J. J., Brussee, R., Fieret, J. H., Klijn, J. G. M., Chadha, S., and Rodenburg, C. J. Occurrence of epidermal growth factor receptors in benign and malignant ovarian tumors and normal ovarian tissues: an immunohistochemical study. J. Cancer Res. Clin. Oncol., *118:* 303–307, 1992.

39. Harlozinska, A., Bar, J. K., Sobanska, E., and Goluda, M. Epidermal growth factor receptor and c-*erb*B-2 oncoproteins in tissue and tumor effusion cells of histopathologically different ovarian neoplasms. Tumor Biol., *19:* 364–373, 1998.

40. Simpson, B. J. B., Phillips, H. A., Lessells, A. M., Langdon, S. P., and Miller, W. R. C-*erb* B growth-factor-receptor proteins in ovarian tumors. Int. J. Cancer, *64:* 202–206, 1995.

41. Bartlett, J. M. S., Langdon, S. P., Simpson, B. J. B., Stewart, M., Katsaros, D., Sismondi, P., Love, S., Scott, W. N., Williams, A. R. W., Lessells, A. M., Macleod, K. G., Smyth, J. F., and Miller, W. R. The prognostic value of epidermal growth factor receptor mRNA expression in primary ovarian cancer. Br. J. Cancer, *73:* 301–306, 1996.

42. Ross, J. S., Yang, F., Kallakury, B. V., Sheehan, C. E., Ambros, R. A., and Muraca, P. J. HER-2/neu oncogene amplification by fluorescence *in situ* hybridization in epithelial tumors of the ovary. Am. J. Clin. Pathol., *11:* 311–316, 1999.

43. Niikura, H., Sasano, H., Sato, S., and Yajima, A. Expression of epidermal growth factor-related proteins and epidermal growth factor receptor in common epithelial ovarian tumors. Int. J. Gynecol. Pathol., *16:* 60–68, 1997.

44. Bast, R. C., Puztai, L., Kerns, B. J., MacDonald, J. A., Jordan, P., Daly, L., Boyer, C. M., Mndolson, J., and Berchuk, A. Coexpression of the HER-2/*neu* (c-*erb*B2) gene product (p185) and the epidermal growth factor receptor (p170) on epithelial ovarian cancers and normal tissues. Hybridoma, *17:* 313–321, 1998.

45. Campiglio, M., Ali, S., Knyazev, P. G., and Ullrich, A. Characteristics of EGFR family-mediated HRG signals in human ovarian cancer. J. Cell. Biochem., *73:* 522–532, 1999.

46. Matsumoto, Y., Ishiko, O., Deguchi, M., Nadagawa, E., and Ogita, S. Cyclo-oxygenase-2 expression in normal ovaries and epithelial ovarian neoplasms. Int. J. Mol. Med., *8:* 31–36, 2001.

47. Rodriguez-Burford, C., Barnes, M. N., Oelschlager, D. K., Myers, R. B., Talley, L. I., Partridge, E. E., and Grizzle, W. E. Effects of nonsteroidal anti-inflammatory agents (NSAIDs) on ovarian carcinoma cell lines: Preclinical evaluation of NSAIDs as chemopreventive agents. Clin. Cancer Res. *8:* 202–209, 2002.

48. Bellacosa, A., De Feo, D., Godwin, A. K., Bell, D. W., Cheng, J. Q., Altomare, D. A., Wan, M., Dubeau, L., Scambia, G., Masciullo, V., Ferrandina, G., Benedetti Panici, P., Mancuso, S., Neri, G., and Testa, J. R. Molecular alterations of the AKT2 oncogene in ovarian and breast carcinomas. Int. J. Cancer, *64:* 280–285, 1995.

49. Iwabuchi, H., Sakamoto, M., Sakunaga, H., Ma, Y. Y., Carcangiu, M. L., Pinkel, D., Yang-Feng, T. L., and Gray, J. W. Genetic analysis of benign, low-grade, and high-grade ovarian tumors. Cancer Res., *55:* 6172–6180, 1995.

50. Bast, R. C., and Mills, B. F. Alterations in oncogenes, tumor suppressor genes, and growth factors associated with epithelial ovarian cancers. *In*: J. M. S. Bartlett (ed.), Ovarian Cancer, Methods and Protocols, Methods in Molecular Medicine, pp. 37–48. Totowa, NJ: Humana Press, Inc., 2000.

51. Shayesteh, L., Lu, Y., Kuo, W-L., Baldocchi, R., Godfrey, T., Collins, C., Pinkel, D., Powell, B., Mills, G. B., and Gray, J. W. PIK3CA is implicated as an oncogene in ovarian cancer. Nat. Genet., *21:* 99–102, 1999.

52. Hu, L., Zaloudek, C., Mills, G. B., Gray, J., and Jaffe, R. B. *In vivo* and *in vitro* ovarian carcinoma growth inhibition by a phophatidylinositol 3-kinase inhibitor (LY294002). Clin. Cancer Res., *6:* 880–886, 2000.

53. Berchuck, A., Kohler, M. F., Marks, J. R., Wiseman, R., Boyd, J., and Bast, R. C., Jr. The p53 tumor suppressor gene frequently is altered in gynecologic cancers. Am. J. Obstet. Gynecol., *170:* 246–252, 1994.

54. Centers for Disease Control Cancer and Steroid Hormone Study. The reduction in risk of ovarian cancer associated with oral contraceptive use. N. Engl. J. Med., *316:* 650–655, 1987.

55. Weiss, N. S., Lyon, J. L., Liff, J. M., Vollmer, W. M., and Daling, J. R. Incidence of ovarian cancer in relation to the use of oral contraceptives. Int. J. Cancer, *28:* 669–671, 1981.

56. The WHO Collaborative Study of Neoplasia and Steroid Contraceptives. Epithelial ovarian cancer and combined oral contraceptives. Int. J. Epidemiol., *8:* 538–545, 1989.

57. Rodriguez, G. C., Walmer, D. K., Cline, M., Krigman, H., Lessey, B. A., Whitaker, R. S., Dodge, R., and Hughes, C. L. Effect of progestin on the ovarian epithelium of macaques: cancer prevention through apoptosis? J. Soc. Gynecol. Invest., *5:* 271–276, 1998.

58. Schildkraut, J. M., Calingaert, B., Marchbanks, P. A., Moorman, P. G., and Rodriguez, G. C. Impact of progestin and estrogen potency in oral contraceptives on ovarian cancer risk. J. Natl. Cancer Inst. (Bethesda), *94:* 32–38, 2002.

59. Hughes, D. E., Dai, A., Tiffee, J. C., Li, H. H., Mundy, G. R., and Boyce, B. F. Estrogen promotes apoptosis of murine osteoclasts mediated by TGF-β. Nat. Med., *2:* 1132–1136, 1996.

60. Um, S-J., Lee, S-Y., Kim, E-J., Han, H-S., Koh, Y-M., Hong, K-J., Sin, H-S., and Park, J-S. Anti-proliferative mechanism of retinoid derivatives in ovarian cancer cells. Cancer Lett., *174*: 127–134, 2001.

61. Zhang, D., Holmes, W. F., Wu, S., Soprano, D. R., and Soprano, K. J. Retinoids and ovarian cancer. J. Cell. Physiol., *185:* 1–20, 2000.

62. Formelli, F., and Cleris, L. Synthetic retinoid fenretinamide is effective against a human ovarian carcinoma xenograft and potentiates cisplatin activity. Cancer Res., *53:* 5374–5376, 1993.

63. Taylor, D. D., Taylor, C. G., Black, P. H., Jiang, C. G., and Chou, I. N. Alterations of cellular characteristics of a human ovarian teratocarcinoma cell line after *in vitro* treatment with retinoids. Differentiation, *43:* 123–130, 1990.

64. DePalo, G., Veronesi, U., Camerini, T., Formelli, F., Mascotti, G., and Boni, C. Can fenretinamide protect women against ovarian cancer. J. Natl. Cancer Inst. (Bethesda), *87:* 146–147, 1995.

65. De Palo, G., Mariani, L., Camerini, T., Marubini, E., Formelli, F., Pasini, B., Decensi, A., and Veronesi, U. Effect of fenretinide on ovarian carcinoma occurrence. Gynecol. Oncol., *86:* 24–27, 2002.

66. Guruswamy, S., Lightfoot, S., Gold, M. A., Hassan, R., Berlin, D., Ivey, R. T., and Benbrook, D. M. Effects of retinoids on cancerous phenotype and apoptosis in organotypic cultures of ovarian carcinoma. J. Natl. Cancer Inst. (Bethesda), *93:* 516–525, 2001.

67. Wu, S., Zhang, D., Donigan, A., Dawson, M. I., Soprano, D. R., and Soprano, K. J. Effects of conformationally restricted synthetic retinoids on ovarian tumor cell growth. J. Cell. Biochem., *68:* 378–388, 1998.

68. Brewer, M., Utzinger, U., Li, Y., Atkinson, E. N., Satterfield, W., Auersperg, N., Richards-Kortum, R., Follen, M., and Bast, R. Fluorescence spectroscopy as a biomarker in a cell culture and in a nonhuman rhesus primate model for ovarian cancer chemopreventive agents. J. Biomed. Opt., *7:* 20–26, 2002.

69. Wyllie, A. H. Apoptosis and carcinogenesis. Eur. J. Cell. Biol., *73:* 189–197, 1997.

70. Zou, C. P., Kurie, J. M., Lotan, D., Zou, C. C., Hong, W. K., and Lotan, R. Higher potency of *N*-(4-hydroxyphenyl) retinamide than all-*trans*-retinoic acid in induction of apoptosis in non-small cell lung cancer cell lines. Clin. Cancer Res., *4:* 1345–1355, 1998.

71. Supino, R., Crosti, M., Clerici, M., Warlters, A., Cleris, L., Zunino, F., and Formelli, F. Induction of apoptosis by fenretinide (4-HPR) in human ovarian carcinoma cells and its association with retinoic acid receptor expression. Int. J. Cancer, *65:* 491–497, 1996.

72. Fanjul, A. N., Delia, D., Pierotti, M. A., Rideout, D., Yu, J. Q., Pfahl, M., and Qiu, J. 4-Hydroxyphenyl retinamide is a highly selective activator of retinoid receptors. J. Biol. Chem., *271:* 22441–22446, 1996.

73. Sheikh, M. S., Shao, Z. M., Li, X. S., Ordonez, J. V., Conley, B. A., Wu, S., Dawson, M. I., Han, Q. X., Chao, W. R., and Quick, T. *N*-(4-Hydroxyphenyl) retinamide (4-HPR)-mediated biological actions involve retinoid receptor-independent pathways in human breast carcinoma. Carcinogenesis (Lond.), *16:* 2477–2486, 1995.

74. Dabal, R., Boyer, C. M., Berchuck, A., Roberts, A., Roche, N., Sporn, M., and Bast, W. Synergistic inhibition of ovarian cancer cell proliferation by TGFβ and retinoic acid (RA) derivatives. Proc. Am. Assoc. Cancer Res., *36:* 635, 1995.

75. Oridate, N., Suzuki, S., Higuchi, M., Mitchell, M., Hong, W., and Lotan, R. Involvement of reactive oxygen species in *N*-(4-hydroxyphenyl) retinamide-induced apoptosis in cervical carcinoma cells. J. Natl. Cancer Inst. (Bethesda), *89:* 1191–1198, 1997.

76. Berchuck, A., Rodriguez, G., Olt, G. J., Whitaker, R., Boente, M. P., Arrick, B. A., Clarke-Pearson, D. L., and Bast, R. C., Jr. Regulation of growth of normal ovarian epithelial cells and ovarian cancer cell lines by transforming growth factor-β. Am. J. Obstet. Gynecol., *166:* 676–684, 1992.

77. Jakowlew, S. B., Moody, T. W., and Mariano, J. M. Transforming growth factor-β receptors in human cancer cell lines: analysis of transcript, protein and proliferation. Anticancer Res., *17:* 1849–1860, 1997.

78. Schneider, S. L., Gollnick, S. O., Grande, C., Pazik, J. E., and Tomasi, T. B. Differential regulation of TGF-β 2 by hormones in rat uterus and mammary gland. J. Reprod. Immunol., *32:* 125–144, 1996.

79. Lindstrom, P., Bergh, A., Holm, I., and Damber, J. E. Expression of transforming growth factor-β 1 in rat ventral prostate and Dunning R3327 PAP prostate tumor after castration and estrogen treatment. Prostate, *29:* 209–218, 1996.

80. Rodriguez, G. C., Nimesh, N. P., Lee, K. L., Bentley, R. C., Walmer, D. K., Cline, M., Whitaker, R. S., Isner, P., Berchuck, A., Dodge, R. K., and Hughes, C. L. Progestin-induced apoptosis in the macaque ovarian epithelium: differential regulation of transforming growth factor-β. J. Natl. Cancer Inst. (Bethesda), *94:* 50–60, 2002.

81. Auersperg, N., Maclaren, I. A., and Kruk, P. A. Ovarian surface epithelium: autonomous production of connective tissue-type extracellular matrix. Biol. Reprod., *44:* 717–724, 1991.

82. Parrott, J. A., Nilsson, E., Mosher, R., Magrane, G., Albertson, D., Pinkel, D., Gray, J., and Skinner, M. K. Stroma-epithelial interactions in the progression of ovarian cancer: influence and source of stromal cells. Mol. Cell. Endocrinol., *175:* 29–39, 2001.

83. Parrott, J. A., Kim, G., Mosher, R., and Skinner, M. K. Expression and action of keratinocyte growth factor (KGF) in normal ovarian surface epithelial and ovarian cancer. Mol. Cell. Endocrinol., *167:* 77–87, 2000.

84. Parrott, J. A., Mosher, R., Kim, G., and Skinner, M. K. Autocrine interactions of keratinocyte growth factor, hepatocyte growth factor, and kit-ligand in the regulation of normal ovarian surface epithelial cells. Endocrinology, *141:* 2532–2539, 2000.

85. Wong, A. S. T., Pelech, S. L., Woo, M., Yim, G., Rosen, B., Ehlen, T., Leung, P., and Auersperg, N. Coexpression of hepatocyte growth factor-Met: an early step in ovarian carcinogenesis? Oncogene, *20:* 1318–1328, 2000.

86. Auersperg, N., Maines-Bandiera, S., Dyck, H. G., and Kruk, P. A. Characterization of cultured human ovarian surface epithelial cells: phenotypic plasticity and premalignant changes. Lab. Investig., *71:* 510–518, 1994.

87. Mourant, J. R., Bigio, I. J., Boyer, J., Conn, R. L., Johnson, T., and Shimada, T. Spectroscopic diagnosis of bladder cancer with elastic light scattering. Lasers Surg. Med., *17:* 350–357, 1995.

88. Ge, Z., Schomacker, K. T., and Nishioka, N. S. Identification of colonic dysplasia and neoplasia by diffuse reflectance spectroscopy and pattern recognition techniques. Appl. Spectrosc., *52:* 833–345, 1998.

89. Koenig, F., Larne, R., Enquist, H., McGovern, F. J., Schomacker, K. T., Kollias, N., and Deutsch, T. F. Spectroscopic measurement of diffuse reflectance for enhanced detection of bladder carcinoma. Urology, *51:* 342–345, 1998.

90. Backman, V., Wallace, M., Perelman, L. T., Arendt, J. T., Gurjar, R., Müller, M. G., Zhang, Q., Zonios, G., Kline, E., McGillican, T., Shapshay, S., Valdez, T., Badizadegan, K., Crawford, J. M., Fitzmaurice, M., Kabani, S., Levin, H. S., Seiler, M., Dasari, R. R., Itzkan, I., Van Dam, J., and Feld, M. S. Detection of preinvasive cancer cells. Nature (Lond.), *406:* 35–36, 2000.

91. Richards-Kortum, R., and Sevick-Muraca, E. Quantitative optical spectroscopy for tissue diagnosis. Annu. Rev. Phys. Chem., *47:* 555–606, 1996.

92. Mahadevan-Jansen, A., and Richards-Kortum, R. Raman spectroscopy for the detection of cancers and precancers. J. Biomed. Opt., *1:* 31–70, 1996.

93. Bigio, I. J., and Mourant, J. R. Ultraviolet and visible spectroscopies for tissue diagnostics: fluorescence spectroscopy and elastic-scattering spectroscopy. Phys. Med. Biol., *42:* 803–814, 1997.

94. Chance, B. Metabolic heterogeneities in rapidly metabolizing tissues. J. Appl. Cardiol., *4:* 207–221, 1989.

95. Gulledge, C. J., and Dewhirst, M. W. Tumor oxygenation: a matter of supply and demand. Anticancer Res., *16:* 741–750, 1996.

96. Brewer, M., Utzinger, U., Silva, E., Gershenson, D., Bast, R. C., Jr., Follen, M., and Richards-Kortum, R. Fluorescence spectroscopy for *in vivo* characterization of ovarian tissue. Lasers Surg. Med., *29:* 128–135, 2001.

97. Brewer, M., Utzinger, U., Silva, E., Gershenson, D., Bast, R. C., Jr., Follen, M., Wharton, J. T., and Richards-Kortum, R. Biomarker modulation in a nonhuman rhesus primate model for ovarian cancer chemoprevention. Cancer Epidemiol. Biomark. Prev., *10:* 889–893, 2001.

98. Blume-Jensen, P., and Hunter, T. Oncogenic kinase signaling. Nature (Lond.), *411:* 355–365, 2001.

99. Slichenmyer, W. J., and Fry, D. W. Anticancer therapy targeting the ErbB family of receptor tyrosine kinases. Semin. Oncol., *28:* 67–79, 2001.

100. Moulder, S. L., Yakes, M., Muthuswamy, S. K., Bianco, R., Simpson, J. F., and Arteaga, C. L. Epidermal growth factor receptor (HER1) tyrosine kinase inhibitor ZD1839 (Iressa) inhibits HER2/*neu* (*erb*B2)-overexpressing breast cancer cells *in vitro* and *in vivo*. Cancer Res., *61:* 8887–8895, 2001.

101. Steinbach, G., Lynch, P. M., Phillips, R. K., Wallace, M. H., Hawk, E., Gordon, G. B., Wakabayashi, N., Saunders, B., Shen, Y., Fujimura, T., Su, L. K., and Levin, B. The effect of celecoxib, a cyclooxygenase-2 inhibitor, in familial adenomatous polyposis. N. Engl. J. Med., *342:* 1946–1952, 2000.

102. Ness, R. B., and Cottreau, C. Possible role of ovarian epithelial inflammation in ovarian cancer. J. Natl. Cancer Inst. (Bethesda), *91:* 1459–1467, 1999.

103. Williams, A. R. W. Pathological assessment of ovarian cancer. *In*: J. M. S. Bartlett (ed.), Ovarian Cancer, Methods and Protocols, Methods in Molecular Medicine, pp. 49–60. Totowa, NJ: Humana Press, Inc., 2000.

104. Zheng, J., Benedict, W. F., Xu, H. J., Hu, S. X., Kim, T. M., Velicescu, M., Wan, M., Cofer, K. F., and Dubeau, L. Genetic disparity between morphologically benign cysts contiguous to ovarian carcinomas and solitary cystadenomas. J. Natl. Cancer Inst. (Bethesda), *87:* 1146–1153, 1995.

105. Liotta, L., and Petricoin, E. F. Molecular profiling of human cancer. Nat. Rev. Genet., *1:* 48–56, 2000.

106. Petricoin, E. F., Ardekani, A. M., Hitt, B. A., Levine, P. J., Fusaro, V. A., Steinberg, S. M., Mills, G. B., Simone, C., Fishman, D. A., Kohn, E. C., and Liotta, L. A. Use of proteomic patterns in serum to identify ovarian cancer. Lancet, *359:* 572–577, 2002.

107. Liotta, L., Kohn, L. C., and Petricoin, E. F. Clinical proteomics, personalized molecular medicine. J. Am. Med. Assoc., *286:* 2211–2214, 2001.