Long-Term Impact of Smoking on Lung Epithelial Proliferation in Current and Former Smokers


Background: Lung cancer risk remains elevated for many years after quitting smoking. To assess using proliferation indices in bronchial tissues as an intermediate endpoint biomarker in lung cancer chemoprevention trials, we determined the relationship between the extent, intensity, and cessation of tobacco smoking and proliferative changes in bronchial epithelial biopsy specimens. Methods: Bronchial biopsy specimens were obtained from up to six epithelial sites in 120 current smokers (median pack-years, 42) and 207 former smokers (median pack-years, 40; median quit-years, 8.1). Sections from the paraffin-embedded specimens were stained with hematoxylin–eosin to determine the metaplasia index and with an antibody to Ki-67 to determine the proliferative (labeling) index for the basal and parabasal (Ki-67 PLI) layers. All statistical tests were two-sided. Results: Biopsy sites with metaplasia had statistically significantly higher Ki-67-labeling indices than those without metaplasia (P<.001) in both current and former smokers. Increased proliferation was observed in multiple biopsy sites, with the average Ki-67 PLI of the subject strongly correlating with the metaplasia index (r = .72 for current smokers; P<.001), even in sites without metaplasia (r = .23 for current smokers; P<.001). In current smokers, the Ki-67 PLI was associated with the number of packs smoked/day (P = .02) but not with smoking years or pack-years. In subjects who had quit smoking, the Ki-67 PLI dropped statistically significantly within 1 year (P = .008) but remained detectable for more than 20 years, even in the absence of squamous metaplasia. Conclusion: Smoking appears to elicit a dose-related proliferative response in the bronchial epithelia of active smokers. Although the proliferative response decreased gradually in former smokers, a subset of individuals had detectable proliferation for many years and may benefit from targeted chemoprevention. Bronchial epithelial proliferation, measured by Ki-67, may provide a useful biomarker in the assessment of lung cancer risk and in the response to chemopreventive interventions. [J Natl Cancer Inst 2001;93:1081–8]

Lung cancer remains the leading cause of cancer death for men and women in the United States, with 169 500 new lung cancer patients and 157 400 lung cancer deaths in the year 2001 (1). Despite improvements in staging and multimodality therapeutic approaches, the overall 5-year survival rate remains at 14% (1). Even if initial treatment is successful, these patients still develop second primary lung cancers at a rate of 1%–5% per year for non-small-cell lung cancer (2,3) and 2%–14% per year for small-cell lung cancer (2). Thus, it is important to focus on early detection or chemoprevention.

Several problems confront lung chemoprevention studies. First, it is difficult to identify individuals at highest lung cancer risk. Epidemiologic studies (4–7) suggest that lung cancer risk is a function of the cumulative tobacco smoking exposure and the intrinsic susceptibility of the exposed individual. Although individuals with a 20-pack-year smoking history have an approximately 10-fold increased lung cancer risk, only 10% may develop lung cancer in their lifetime. Moreover, lung cancer risk remains considerably elevated for many years after quitting smoking, such that nearly half of the

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newly diagnosed lung cancer cases in the United States occur in former smokers (8,9). Thus, lung cancer prevention studies that use lung cancer incidence as a primary endpoint require tens of thousands of subjects and tens of years of duration for adequate statistical interpretation. Unfortunately, all lung cancer prevention studies reported so far have negative results and, in some cases, individuals who continued to smoke during the intervention had an adverse outcome (3,10–12). Second, it is difficult to identify potentially efficacious chemopreventive agents (13,14). Unfortunately, little is known about lung tumorigenesis in humans or which molecular pathways to best target for chemoprevention. Therefore, biomarkers are needed to identify individuals at the highest risk for lung cancer and to provide intermediate surrogate markers of response. The development and incorporation of such biomarkers into chemoprevention trials would reduce the numbers of subjects required for adequate statistical evaluation, decrease the time needed to assess biologic efficacy, and help identify new molecular targets for intervention (15).

Lung tumorigenesis involves a field carcinomaization process whereby the lung is exposed to a carcinogenic insult (e.g., tobacco smoke), setting off a chronic pattern of tissue damage and wound healing (16). Chronic carcinogenic insult initiates a multistep process marked by cumulative histologic and genetic changes and proliferative clonal outgrowths throughout the lung (17,18). The development of metaplasia is one such step that has been used as a biomarker. In a study of 20-pack-year smokers (19), where bronchial biopsy specimens were obtained from six independent sites, squamous metaplasia was evident in at least one of the six sites in nearly 80% of the smokers. However, if the subjects stopped smoking, the metaplasia index (MI) fell from 37% to 17% within 6 months, and squamous metaplasia disappeared altogether in 50% of the subjects. Thus, the use of bronchial metaplasia as a biomarker of risk and response in chemoprevention trials involving former smokers is problematic.

Because abnormal epithelial proliferation is one hallmark of tumorigenesis, it was of interest to explore the feasibility of using a proliferation biomarker to assess tobacco smoke-associated bronchial changes. Although proliferating cell nuclear antigen (PCNA) was shown to correlate well with histologic changes in the lungs of chronic smokers (20), there is some concern regarding its use as a proliferation marker because PCNA is also a component of a DNA repair pathway, which may be active in chronically damaged tissues, such as the smoking-exposed lung (21).

A number of additional proliferation markers are available that identify different aspects of proliferating cells (22). For example, Ki-67 is a proliferation marker that is expressed in all phases of cycling cells but not in resting cells (23). In lung tumors, the fraction of Ki-67-positive cells was generally increased and of some prognostic value, especially when used in combination with other tumor parameters (24,25). Increased numbers of Ki-67-positive cells have also been detected in the aerodigestive tract epithelium of smokers compared with nonsmokers (26,27). However, little is known about the relationship between Ki-67 expression, smoking history, and the long-term consequences of quitting smoking on the proliferation of bronchial epithelium.

In this report, we determined the feasibility of Ki-67 staining as a biomarker for use in chemoprevention trials. In particular, we determined the relationship between the Ki-67-labeling index in the bronchial epithelium of chronic smokers, squamous metaplasia, and the subject’s smoking characteristics and determined the impact of quitting smoking on the proliferative activity in the bronchial epithelium.

SUBJECTS AND METHODS

Subject Selection and Clinical Trial Design

Baseline tissue samples from 120 current and 207 former smokers participating in two randomized chemoprevention trials were analyzed in this report. Current smokers were defined as active smokers or smokers who had quit smoking within 1 year of registration onto the respective chemoprevention trials; former smokers were those who quit smoking for at least 1 year at the time of registration. Smoking history was measured by packs/day, smoke-years, and pack-years, which is the product of packs/day and smoke-years.

The first trial was designed to study the chemopreventive effect of N-(4-hydroxyphenyl)retinamide in smokers with a minimum of 20 pack-years of smoking history and detectable bronchial squamous metaplasia and/or dysplasia at the time of the screening bronchoscopy. Study subjects may have had a prior tobacco-related cancer but must have been tumor free for at least 6 months before enrollment (28). One hundred thirty-nine smokers were registered in the first trial from April 1994 through December 1998 and, among them, 137 (120 current smokers and 17 former smokers; 80 randomly assigned and 57 not randomly assigned) had tissue samples available for the biomarker analysis. The presence of squamous metaplasia was required for the subjects to be randomly assigned to receive the chemopreventive agent or placebo but was not necessary for the subjects to be included in this report.

The second ongoing, randomized trial is evaluating the effect of 13-cis-retinoic acid plus α-tocopheryl acetate versus 9-cis-retinoic acid versus placebo in former smokers. To be eligible for receiving randomly assigned treatment in the trial, former smokers needed to have a minimum of 20 pack-years of smoking history but did not need to have squamous metaplasia or dysplasia. One hundred ninety former smokers were registered in the trial from November 1995 through June 2000 (target sample size for registration = 225). All registered subjects in both trials, whether randomly assigned or not, who had available baseline tissue samples were included in this report.

Both trials were approved by the Institutional Review Board, and all study subjects provided written informed consent.

Bronchial Biopsy and Tissue Preparation

A baseline bronchoscopy was performed for all participants at the time of registration for their respective chemoprevention trial. Biopsy specimens were taken at six predetermined sites in the bronchial tree, including the main carina, the bifurcation of the right upper lobe and the mainstem bronchus, the bifurcation of the right middle lobe and right lower lobe, the bifurcation of the left upper lobe and lingula, the medial bronchus of the right lower lobe, and the anterior bronchus of the left lower lobe. The biopsy specimens were fixed in 10% buffered formalin, embedded in paraffin, and sectioned. The first 10 4-μm tissue sections from each biopsy site were stained with hematoxylin–eosin and evaluated for the presence of squamous metaplasia and dysplasia. The MI was calculated as the percentage of biopsy sections exhibiting squamous metaplasia out of the total number of sections examined (19).

Immunohistochemical Analysis of Ki-67

One 4-μm tissue section from each biopsy specimen was immunohistochemically stained for Ki-67 expression and evaluated for proliferative activity. A positive control section of HeLa cells was placed on each sample slide to serve as an internal control for the immunostaining procedure. The tissue sections were deparaffinized in xylene, rehydrated through a series of alcohols, and immersed in 3% hydrogen peroxide in methanol for 15 minutes to block endogenous peroxidase activity. Antigen retrieval was accomplished by placing slides in citrate buffer (pH = 6.0) and heating in a 800-W microwave at 100% power for two 4-minute periods. The slides were then blocked in 2% horse serum in phosphate-buffered saline (PBS) at 57 °C for 30 minutes, treated with a 1:10 dilution of MIB 1 mouse anti-Ki-67 antibody (Zymed Laboratories Inc., South San Francisco, CA), and incubated overnight at 4 °C. After the slides were brought to room temperature for 15 minutes and sequentially washed in PBSD.
lung epithelial cell proliferation was used to test for equal median between two conditions. Box plots were used to display the distribution of covariates, as well as the cell proliferation indices (Ki-67 results from the main analysis. Analyses of the Ki-67-labeling indices are presented both on a per-site basis and on a per-subject basis (the average of all biopsy specimens that could be evaluated within a participant).

Statistical Analysis

Summary statistics, including frequency tabulation, mean, standard deviation, median, and range, were given to characterize the distribution of covariates, as well as the cell proliferation indices (Ki-67 labeling and metaplasia indices in current and former smokers). Table 1 shows that Ki-67 labeling was readily apparent in the basal and parabasal layers of the bronchial epithelium in both current and former smokers, even in the absence of squamous metaplasia. Current smokers had higher Ki-67-labeling indices and MI than did former smokers on a per-subject basis ($P<.001$; Wilcoxon rank sum test; Table 1). The scatter plots in Fig. 2 show Ki-67-labeling indices in the basal and parabasal layers were highly correlated both in current (Spearman rank correlation, $r = .70$) and former ($r = .74$) smokers. However, the mean Ki-67-labeling index in the parabasal layer was approximately twofold higher than that in the basal layer (Table 1). Although the basal and parabasal Ki-67-labeling indices were highly correlated with MI (Fig. 2), the correlation was stronger for the parabasal layer (in current smokers, $r = .59$ versus $.72$ for basal versus parabasal layers, respectively; in the absence of squamous metaplasia. Current smokers had higher Ki-67-labeling indices and MI than did former smokers on a per-subject basis ($P<.001$; Wilcoxon rank sum test).

Table 1. Demographics and Ki-67-labeling and metaplasia indices in current and former smokers*

<table>
<thead>
<tr>
<th>Demographic</th>
<th>Current smokers (n = 120)</th>
<th>Former smokers (n = 207)</th>
<th>All subjects (n = 327)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sex</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Female</td>
<td>52 (43%)</td>
<td>87 (42%)</td>
<td>139 (43%)</td>
</tr>
<tr>
<td>Male</td>
<td>68 (57%)</td>
<td>120 (58%)</td>
<td>188 (57%)</td>
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<tr>
<td>Ethnicity/race</td>
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<td></td>
<td></td>
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<tr>
<td>White</td>
<td>110 (92%)</td>
<td>188 (91%)</td>
<td>298 (91%)</td>
</tr>
<tr>
<td>Other</td>
<td>10 (8%)</td>
<td>19 (9%)</td>
<td>29 (9%)</td>
</tr>
<tr>
<td>Age, y</td>
<td>51.9 ± 9.9</td>
<td>57.6 ± 9.7</td>
<td>55.6 ± 1.0</td>
</tr>
<tr>
<td></td>
<td>52.0 (30–77)</td>
<td>57.4 (34–78)</td>
<td>55.3 (30–78)</td>
</tr>
<tr>
<td>History of smoking-related cancers</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Yes</td>
<td>15 (13%)</td>
<td>33 (16%)</td>
<td>48 (15%)</td>
</tr>
<tr>
<td>No</td>
<td>105 (88%)</td>
<td>174 (84%)</td>
<td>279 (85%)</td>
</tr>
<tr>
<td>Packs/day</td>
<td>1.5 ± 0.6</td>
<td>1.8 ± 0.8</td>
<td>1.7 ± 0.7</td>
</tr>
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<td></td>
<td>1.3 (0.3–3.0)</td>
<td>1.5 (0.8–4.0)</td>
<td>1.5 (0.3–4.0)</td>
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<tr>
<td>Smoke-years</td>
<td>32.7 ± 10.0</td>
<td>28.1 ± 8.8</td>
<td>29.8 ± 9.5</td>
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<tr>
<td></td>
<td>30 (14–55)</td>
<td>28 (12–50)</td>
<td>30 (12–55)</td>
</tr>
<tr>
<td>Pack-years</td>
<td>48.5 ± 25.3</td>
<td>50.1 ± 29.0</td>
<td>49.5 ± 27.7</td>
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<tr>
<td></td>
<td>42 (15–150)</td>
<td>40 (20–152)</td>
<td>40 (15–152)</td>
</tr>
<tr>
<td>Quit-years</td>
<td>0.37 ± 0.28</td>
<td>10.51 ± 9.03</td>
<td>9.28 ± 0.99</td>
</tr>
<tr>
<td></td>
<td>0.26 (0.01–0.83)†</td>
<td>8.09 (1.01–48.06)‡</td>
<td>7.48 (0.01–48.06)‡</td>
</tr>
<tr>
<td>Basal layer</td>
<td>6.3 ± 4.2</td>
<td>2.4 ± 2.2</td>
<td>3.8 ± 3.6</td>
</tr>
<tr>
<td>Ki-67-labeling index§</td>
<td>6.0 (0.4–22.7)</td>
<td>1.9 (0–16.7)</td>
<td>2.6 (0–22.7)</td>
</tr>
<tr>
<td>Parabasal layer</td>
<td>12.7 ± 8.2</td>
<td>5.7 ± 5.7</td>
<td>8.3 ± 7.5</td>
</tr>
<tr>
<td>Ki-67-labeling index§</td>
<td>10.7 (0.6–38.1)</td>
<td>3.6 (0–35.6)</td>
<td>5.8 (0–38.1)</td>
</tr>
<tr>
<td>Metaplasia index§</td>
<td>27.9 ± 26.7</td>
<td>5.9 ± 11.2</td>
<td>14.0 ± 21.2</td>
</tr>
<tr>
<td></td>
<td>18.7 (0–100)</td>
<td>0 (0–66.7)</td>
<td>0 (0–100)</td>
</tr>
</tbody>
</table>

*For the continuous variables, mean ± standard deviation and median (range) are shown in the 1st and 2nd line, respectively.
†Summary statistics were based on 15 subjects who quit smoking within 1 year.
‡Summary statistics were based on 222 subjects who quit smoking.
§Basal- and parabasal-layer Ki-67-labeling indices were calculated as the percentage of positively stained cells. Metaplasia index was calculated as the percentage of tissue sections having metaplasia. All three indices were statistically significantly different between current and former smokers ($P<.001$; Wilcoxon rank sum test).
former smokers, $r = .40$ versus .47 for basal versus parabasal layers, respectively). Despite this strong correlation, there were many outliers with high Ki-67 PLI, especially in former smokers with low MI, suggesting that Ki-67-labeling indices may offer additional information beyond the MI.

In current smokers, 34.5% (205 of 595) of the biopsy sites had squamous metaplasia, compared with only 7.8% (75 of 958) in former smokers (Fig. 3, A). Biopsy sites with squamous metaplasia consistently had higher Ki-67 PLI than those without metaplasia in both current (median, 20.5 versus 6.3; $P<.001$; Wilcoxon rank sum test) and former (median, 21.6 versus 4.6; $P<.001$) smokers (Fig. 3, A). For biopsy sites with squamous metaplasia, there was no difference in Ki-67 PLI between current and former smokers ($P = .35$). By contrast, for biopsy sites without squamous metaplasia, current smokers had higher Ki-67 levels than former smokers (median, 6.3 versus 2.7; $P<.001$) (Fig. 3, A). Of interest, sites with increased Ki-67 PLI were observed frequently, even when these sites did not exhibit squamous metaplasia. In fact, in sites without squamous metaplasia, the Ki-67 PLI was still statistically significantly correlated with the MI in both the current and former smokers ($r = .23$ [$P<.001$] and $r = .15$ [$P<.001$], respectively; see supplementary Fig. 1 at the Journal’s Web site [http://jnci.oup-journals.org]), suggesting that the Ki-67 PLI at any one site reflects the level of tobacco-induced, abnormal changes present throughout the lung. Within each subject, the variability in the Ki-67-labeling index increased with the mean Ki-67 value. Variance component analysis on the log-transformed Ki-67 PLI found that the between-subject and within-subject variances were 0.099 and 0.214, respectively, suggesting that multiple biopsy specimens from each individual are required to best estimate the proliferative activity present throughout the lung.

To better understand the factors influencing the correlation between proliferation and MI, we next examined their relationship with medical/demographic variables and smoking history in active smokers. Sex, ethnicity/race, and age did not correlate with proliferation or MI, but a trend toward higher Ki-67 BLI was observed in subjects with a history of smoking-related cancer ($P = .10$; Wilcoxon rank sum test). In current smokers, proliferation did not correlate with smoke-years or pack-years, and MI weakly correlated with pack-years ($r = .19; P = .054$). Moreover, in active smokers, smoking intensity (packs/day) positively correlated with Ki-67 BLI, Ki-67 PLI, and MI ($P = .01, P = .02$, and $P = .001$, respectively). However, the degree of variability between individuals who smoked comparable numbers of packs/day was high (see supplementary Fig. 2 at the Journal’s website), suggesting that there were large differences in susceptibility to tobacco exposure between individuals. The association between smoking intensity and proliferation or MI was not seen in former smokers.

Of interest, in subjects who quit smoking, Ki-67 BLI, Ki-67 PLI, and MI were negatively correlated with number of years of smoking cessation ($r = -.16\ [P = .02], r = -.15\ [P = .02]$ and $r = -.15\ [P = .02]$, respectively). We then further examined the kinetics between these parameters and years of smoking cessation. After adjustment for the squamous metaplasia status, the proliferation indices were statistically significantly decreased within the first year of smoking cessation ($Q [\text{quit}]<1; P = .008$; linear mixed-effect model for Ki-67 PLI), further decreased in years 1–2 ($Q_1–2$) and in years 2–5 ($Q_2–5$) after quitting smoking, and decreased only slightly thereafter (Fig. 3, B). In addition, the kinetics of the reduction in the MI after quitting smoking were more rapid than that of the proliferation indices, with the median MI decreasing from 26.7 to 0 within the first year and remaining at 0 thereafter. Only 28% of the former smokers had evidence of squamous metaplasia. The strong association between the reduction in Ki-67 PLI and quitting smoking after adjustment for squamous metaplasia supports that notion that Ki-67 assessment provides additional information beyond that of histology. More important, Ki-67 PLI remained measurable for many years after smoking cessation, and high Ki-67 PLI and Ki-67 BLI could still be detected even 20 years after quitting smoking in a subset of former smokers.

DISCUSSION

The goal of this study was to explore the potential for use of proliferative activity in bronchial epithelium as a biomarker for lung cancer risk and chemopreventive responses in chronic smokers. The results provided two important findings. First, Ki-67-labeling indices were increased throughout the bronchial epithelium of active smokers and were correlated with smoking intensity (packs/day) and the presence of squamous metaplasia. Second, Ki-67-labeling indices were decreased in former smokers in a time-dependent manner. However, high Ki-67-labeling indices could still be detected in the bronchial epithelium in some former smokers long after they had quit smoking.
Our results have several implications for the role of smoking in the pathogenesis of lung cancer (31,32). The finding that a dose–response relationship exists between Ki-67-labeling indices and the intensity of smoking exposure measured by the number of packs smoked per day in active smokers suggests that smoking exposure elicits proliferative activity in the lung, perhaps associated with chronic wound healing that occurs after smoking-induced tissue damage. Moreover, the findings that 1) the levels of proliferation decreased in a time-dependent fashion after quitting smoking and 2) the relationship between the level of prior smoking intensity and proliferative activity was not seen after quitting smoking further supports a direct relationship between smoking exposure and proliferative activity.

Although the proliferative activity differed greatly among individuals who had comparable smoking histories, those who had increased proliferation at one lung site tended to have increased proliferation at other sites. These findings suggest that, although individuals may differ in their response to carcinogenic insult, the impact of the carcinogenic exposure can be detected throughout the lung, in any area from which a biopsy specimen can be taken. This observation provides direct support for the field-cancerization hypothesis. While the basis for interindividual susceptibility is not well understood, molecular epidemiologic studies (33,34) have identified several genetic and physiologic factors (i.e., cytochrome P450 and glutathione S-transferase polymorphisms, chromosome damage by mutagens, and DNA repair activities) that distinguish individuals with and without lung cancer. It is, therefore, of considerable interest to examine the relationship between the various intrinsic susceptibility factors, smoking histories, and proliferative activity in the lungs of smokers. Although the relationship between Ki-67-labeling indices and lung cancer risk is not yet known, it is intriguing that some individuals with a history of smoking-associated cancer had higher levels of proliferative activity in their bronchial epithelium, perhaps reflecting their known increased risk for second primary cancers.

Proliferative activity in the bronchial epithelium decreased with time in former smokers following smoking cessation. However, this study was cross-sectional in nature, with the conclusions based on single measurements of different individuals at different stages in their smoking history. Nevertheless, a statistically significant drop in proliferation within the first year of quitting smoking supports our previous longitudinal observations that used the proliferation marker PCNA (20). The kinetics of the reduction in the Ki-67 PLI was slower than in the Ki-67 BLI. This suggests that the factors that control epithelial proliferation may be different between the basal layer, thought to harbor the reserve progenitor cells for tissue renewal, and the parabasal layer, thought to harbor the expanding pool of committed cells. Previously, we noted an association between PCNA expression and epidermal growth factor receptor expression in bronchial biopsy specimens from both active smokers and those who quit smoking dur-

![Fig. 2. Pairwise scatter plots for basal-layer Ki-67-labeling index, parabasal-layer Ki-67-labeling index, and metaplasia index in current and former smokers. The subject was used as the analysis unit. The nonparametric regression lines with lowess smoothing are shown in the plot. The Spearman’s rank correlation coefficient (r) is indicated on the Fig. For all plots, the P value for testing zero correlation between any two markers was <.001.](attachment:image.png)
ing the first 6 months of chemopreventive intervention (20). We and others (35,36) have detected clonal genetic changes in these same biopsy specimens that might impact cell cycle regulation (i.e., loss of heterozygosity at chromosomes 9p and 3p involving genes for p16, fragile histidine triad, and other putative tumor suppressor genes). These biopsy specimens thus provide a unique opportunity to better understand the molecular forces driving proliferative clonal outgrowth in the lungs of current and former smokers.

Our results have several implications for lung cancer prevention. Primary chemoprevention trials that rely on the development of cancer as a primary endpoint are difficult to accomplish because of the large numbers of subjects and long follow-up times required. It is, therefore, important to identify surrogate endpoint biomarkers (37,38). Although histologic changes reflect abnormal regulation of the lung epithelia, they have some drawbacks as biomarkers. For example, squamous metaplasia can reflect a reactive condition and may rapidly disappear in individuals who quit smoking. This can create problems interpreting chemopreventive responses in former smokers where bronchial squamous metaplasia is an infrequent event. Moreover, in chemoprevention trials where the incidence of squamous metaplasia varies widely among individuals, large sample sizes would be required for testing treatment effects. Furthermore, the MI is a qualitative endpoint, and its subjectivity makes it prone to interobserver variations.

By contrast, Ki-67-labeling indices possess several desirable properties for their use as biomarkers in chemoprevention trials. First, Ki-67-labeling indices can be measured in former smokers long after they have quit smoking. Second, Ki-67-labeling indices can be potentially modulated by chemopreventive interventions. Third, Ki-67-labeling indices correlate with the MI so that elevated levels can be detected even in bronchial sites that lack histologic evidence of squamous metaplasia. Thus, Ki-67-labeling index at one site in the lung may reflect more global changes occurring throughout the lung. However, variance-component analysis suggests that multiple biopsy specimens are required to gain an adequate estimate for the whole lung.

Ki-67-labeling indices may also be useful markers for lung cancer risk. There was considerable interindividual variation

Fig. 3. Panel A: box plots for the parabasal-layer Ki-67-labeling index by smoking status and squamous metaplasia. The biopsy specimen site was used as the analysis unit. The y-axis represents the parabasal-layer Ki-67-labeling index expressed as the percentage of positively stained cells. The number of biopsy specimens (N) with adequate staining in each group is shown. CUR-NEG = current smokers without squamous metaplasia; CUR-POS = current smokers with squamous metaplasia; FOR-NEG = former smokers without squamous metaplasia, and FOR-POS = former smokers with squamous metaplasia. Panel B: box plots for the basal-layer Ki-67-labeling index, parabasal-layer Ki-67-labeling index, and metaplasia index by groups of smokers as a function of time after quitting smoking. For the upper and middle panels, the y-axis represents the Ki-67-labeling indices expressed as the percentage of positively stained cells. For the lower panel, the y-axis represents the metaplasia index expressed as the percentage of biopsy specimens with squamous metaplasia of the total number of sections examined. The number of subjects (N) with evaluable biopsy specimens in each group is shown. SMK = active smokers; Q (quit)<1 = quit smoking within 1 year of registration; Q1–2 = quit smoking from 1 to 2 years of registration, etc. For panels A and B, the solid box indicates the location of the middle 50% of the data (1st to 3rd quartile), with the median marked in the center as a white stripe. The location of the mean is identified by an X. The brackets indicate the data range from the end of the middle box up to 1.5 times the interquartile range. Data outside the brackets are marked with individual bars.
in the proliferative activity between those with comparable smoking histories, suggesting that Ki-67-labeling indices may reflect differential individual downstream consequences of both carcinogen exposure and intrinsic susceptibility factors. Moreover, subjects with a history of smoking-related cancer, known to be at an increased lung cancer risk, had elevated Ki-67 levels. It is, therefore, intriguing that some individuals continued to have relatively high proliferative levels in their lung epithelium for many years after they quit smoking. Previously, we showed that normal and premalignant epithelia adjacent to head and neck cancers (i.e., epithelium in a tissue field with a 100% chance of developing a tumor) had increased proliferation levels, suggesting that the degree of abnormal epithelial proliferation may be related to long-term lung cancer risk (39). Continued follow-up of the individuals participating in our chemoprevention trials will provide insight into the role of Ki-67 labeling as a marker of lung cancer risk.

Although dysregulated proliferation is a hallmark in tumorigenesis, it is unclear whether it is important in the evolution of a tumor. There is some evidence (40) to suggest that the loss of cell cycle control can lead to increased genetic instability, thus accelerating the accumulation of genetic changes important for tumor development. Similarly, dysregulated epithelial proliferation associated with altered epithelial–stromal interactions has also been associated with increased genetic instability and subsequent tumor development (41). The same biopsy specimens examined in this study are also being examined for chromosome instability (42), which will provide a unique opportunity to explore the relationship between altered epithelial proliferation and genetic instability. Several chemoprevention candidate agents are hypothesized to directly or indirectly target proliferative pathways (14). The assessment of Ki-67 labeling as a biomarker should prove to be highly useful in chemoprevention studies, especially when considered with measurements of other markers known to influence tumorigenesis.

REFERENCES


NOTES

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