METHOD FOR TREATING GEFITINIB RESISTANT CANCER

BACKGROUND

[001] Epithelial cell cancers, for example, prostate cancer, breast cancer, colon cancer, lung cancer, pancreatic cancer, ovarian cancer, cancer of the spleen, testicular cancer, cancer of the thymus, etc., are diseases characterized by abnormal, accelerated growth of epithelial cells. This accelerated growth initially causes a tumor to form. Eventually, metastasis to different organ sites can also occur. Although progress has been made in the diagnosis and treatment of various cancers, these diseases still result in significant mortality.

[002] Lung cancer remains the leading cause of cancer death in industrialized countries. Cancers that begin in the lungs are divided into two major types, non-small cell lung cancer and small cell lung cancer, depending on how the cells appear under a microscope. Non-small cell lung cancer (squamous cell carcinoma, adenocarcinoma, and large cell carcinoma) generally spreads to other organs more slowly than does small cell lung cancer. About 75 percent of lung cancer cases are categorized as non-small cell lung cancer (e.g., adenocarcinomas), and the other 25 percent are small cell lung cancer. Non-small cell lung cancer (NSCLC) is the leading cause of cancer deaths in the United States, Japan and Western Europe. For patients with advanced disease, chemotherapy provides a modest benefit in survival, but at the cost of significant toxicity, underscoring the need for therapeutic agents that are specifically targeted to the critical genetic lesions that direct tumor growth (Schiller JH et al., N Engl J Med, 346: 92-98, 2002).

[003] Epidermal growth factor receptor (EGFR) is a 170 kilodalton (kDa) membrane-bound protein expressed on the surface of epithelial cells. EGFR is a member of the growth factor receptor family of protein tyrosine kinases, a class of cell cycle regulatory molecules. (W. J. Gullick et al., 1986, Cancer Res., 46:285-292). EGFR is activated when its ligand (either EGF or TGF-α) binds to the extracellular domain, resulting in autophosphorylation of the receptor's intracellular tyrosine kinase domain (S. Cohen et al., 1980, J. Biol. Chem., 255:4834-4842; A. B. Schreiber et al., 1983, J. Biol. Chem., 258:846-853).

[004] EGFR is the protein product of a growth promoting oncogene, erbB or ErbB1, that is but one member of a family, i.e., the ERBB family of protooncogenes, believed to play pivotal roles in the development and progression of many human cancers. In particular, increased expression of EGFR has been observed in breast, bladder, lung, head, neck and stomach cancer as well as glioblastomas. The ERBB family of oncogenes encodes four, structurally-related transmembrane receptors, namely, EGFR, HER-2/neu (erbB2), HER-3 (erbB3) and HER-4 (erbB4). Clinically, ERBB oncogene amplification and/or receptor overexpression in tumors have been reported to correlate with disease recurrence and poor patient prognosis, as well as with responsiveness in therapy. (L. Harris et al., 1999, Int. J. Biol. Markers, 14:8-15; and J. Mendelsohn and J. Baselga, 2000, Oncogene, 19:6550-6565).

[005] EGFR is composed of three principal domains, namely, the extracellular domain (ECD), which is glycosylated and contains the ligand-binding pocket with two cysteine-rich regions; a short transmembrane domain, and an intracellular domain that has intrinsic tyrosine kinase activity. The transmembrane region joins the ligand-binding domain to the intracellular domain. Amino acid and DNA sequence analysis, as well as studies of nonglycosylated forms of EGFR, indicate that the protein backbone of EGFR has a mass of 132 kDa, with 1186 amino acid residues (A. L. Ullrich et al., 1984, Nature, 307:418-425; J. Downward et al., 1984, Nature, 307:521-527; C. R. Carlin et al., 1986, Mol. Cell. Biol., 6:257-264; and F. L. V. Mayes and M. D. Waterfield, 1984, The EMBO J., 3:531-537).

[006] The binding of EGF or TGF-α to EGFR activates a signal transduction pathway and results in cell proliferation. The dimerization, conformational changes and internalization of EGFR molecules function to transmit intracellular signals leading to cell growth regulation (G. Carpenter and S. Cohen, 1979, Ann. Rev. Biochem., 48:193-216). Genetic alterations that affect the regulation of growth factor receptor function, or lead to overexpression of receptor and/or ligand, result in cell proliferation. In addition, EGFR has been determined to play a role in cell differentiation, enhancement of cell motility, protein secretion, neovascularization, invasion, metastasis and resistance of cancer cells to chemotherapeutic agents and radiation. (M.-J. Oh et al., 2000, Clin. Cancer Res., 6:4760-4763).

[007] A variety of inhibitors of EGFR have been identified, including a number already undergoing clinical trials for treatment of various cancers. For a recent summary, see de Bono, J. S. and Rowinsky, E. K. (2002), "The ErbB Receptor Family: A Therapeutic Target For Cancer", *Trends in Molecular Medicine,* 8, S19-26.

[008] A promising set of targets for therapeutic intervention in the treatment of cancer includes the members of the HER-kinase axis. They are frequently upregulated in solid epithelial tumors of, by way of example, the prostate, lung and breast, and are also upregulated in glioblastoma tumors. Epidermal growth factor receptor (EGFR) is a member of the HER-kinase axis, and has been the target of choice for the development of several different cancer therapies. EGFR tyrosine kinase inhibitors (EGFR-TKIs) are among these therapies, since the reversible phosphorylation of tyrosine residues is required for activation of the EGFR pathway. In other words, EGFR-TKIs block a cell surface receptor responsible for triggering and/or maintaining the cell signaling pathway that induces tumor cell growth and division. Specifically, it is believed that these inhibitors interfere with the EGFR kinase domain, referred to as HER-1. Among the more promising EGFR-TKIs are three series of compounds: quinazolines, pyridopyrimidines and pyrrolopyrimidines.

[009] Two of the more advanced compounds in clinical development include Gefitinib (compound ZD1839 developed by AstraZeneca UK Ltd.; available under the tradename IRESSA; hereinafter "IRESSA") and Erlotinib (compound OSI-774 developed by Genentech, Inc. and OSI Pharmaceuticals, Inc.; available under the tradename TARCEVA; hereinafter "TARCEVA"); both have generated encouraging clinical results. Conventional cancer treatment with both IRESSA and TARCEVA involves the daily, oral administration of no more than 500 mg of the respective compounds. In May, 2003, IRESSA became the first of these products to reach the United States market, when it was approved for the treatment of advanced non-small cell lung cancer patients.

[0010] IRESSA is an orally active quinazoline that functions by directly inhibiting tyrosine kinase phosphorylation on the EGFR molecule. It competes for the adenosine triphosphate (ATP) binding site, leading to suppression of the HER-kinase axis. The exact mechanism of the IRESSA response is not completely understood, however, studies suggest that the presence of EGFR is a necessary prerequisite for its action.

[0011] A significant limitation in using these compounds is that recipients thereof may develop a resistance to their therapeutic effects after they initially respond to therapy, or they may not respond to EGFR-TKIs to any measurable degree at all. The response rate to EGFR-TKIs varies between different ethnic groups. At the low end of EGFR-TKI responders, in some populations, only 10-15 percent of advanced non-small cell lung cancer patients respond to EGFR kinase inhibitors. Thus, a better understanding of the molecular mechanisms underlying sensitivity to IRESSA and TARCEVA would be extremely beneficial in targeting therapy to those individuals whom are most likely to benefit from such therapy.

[0012] There is a significant need in the art for a satisfactory treatment of cancer, and specifically epithelial cell cancers such as lung, ovarian, breast, brain, colon and prostate cancers, which incorporates the benefits of TKI therapy and overcoming the non-responsiveness exhibited by patients. Such a treatment could have a dramatic impact on the health of individuals, and especially older individuals, among whom cancer is especially common.

SUMMARY

[0013] The inventors of the present invention have surprisingly discovered that irreversible EGFR inhibitors are effective in the treatment of cancer in subjects who are no longer responding to gefitinib and/or erlotinib therapies. Thus, in one embodiment, the present invention provides a method for the treatment of gefitinib and/or erlotinib resistant cancer. In this embodiment, progression of cancer in a subject is monitored at a time point after the subject has initiated gefitinib and/or erlotinib treatment. Progression of the cancer is indicative of cancer that is resistant to gefitinib and/ or erlotinib treatment

and the subject is administered a pharmaceutical composition comprising an irreversible epidermal growth factor receptor (EGFR) inhibitor.

[0014] In preferred embodiments, the irreversible EGFR inhibitor EKB-569, HKI-272 or HKI-357. Alternatively, the irreversible EGFR inhibitor may be any compound which binds to cysteine 773 of EGFR (SEQ ID NO: 1).

[0015] The progression of cancer may be monitored by methods well known to those of skill in the art. For example, the progression may be monitored by way of visual inspection of the cancer, such as, by means of X-ray, CT scan or MRI. Alternatively, the progression may be monitored by way of tumor biomarker detection.

[0016] In one embodiment, the patient is monitored at various time points throughout the treatment of the cancer. For example, the progression of a cancer may be monitored by analyzing the progression of cancer at a second time point and comparing this analysis to an analysis at a first time point. The first time point may be before or after initiation of gefitinib and/ or erlotinib treatment and the second time point is after the first. An increased growth of the cancer indicates progression of the cancer.

[0017] In one embodiment, the progression of cancer is monitored by analyzing the size of the cancer. In one embodiment, the size of the cancer is analyzed via visual inspection of the cancer by means of X-ray, CT scan or MRI. In one embodiment, the size of the cancer is monitored by way of tumor biomarker detection.

[0018] In one embodiment, the cancer is epithelial cell cancer. In one embodiment, the cancer is gastrointestinal cancer, prostate cancer, ovarian cancer, breast cancer, head and neck cancer, esophageal cancer, lung cancer, non-small cell lung cancer, cancer of the nervous system, kidney cancer, retina cancer, skin cancer, liver cancer, pancreatic cancer, genital-urinary cancer and bladder cancer.

[0019] In one embodiment, the size of the cancer is monitored at additional time points, and the additional time points are after the second time point.

[0020] In one embodiment, the later time point is at least 2 months after the preceding time point. In one embodiment, the later time point is at least 6 months after preceding time point. In one embodiment, the later time point is at least 10 months after

preceding time point. In one embodiment, the later time point is at least one year after preceding time point.

[0021] In another embodiment, the present invention provides a method of treating cancer, comprising administering to a subject having a mutation in EGFR, namely, a substitution of a methionine for a threonine at position 790 (T790M) of SEQ ID. No. 1, a pharmaceutical composition comprising an irreversible EGFR inhibitor. The T790M mutation confers resistance to gefitinib and/ or erlotinib treatment.

BRIEF DESCRIPTION OF THE FIGURES

[0022] Figures 1A-1B show EGFR sequence analysis in recurrent metastatic lesions from two NSCLC patients with acquired gefitinib resistance. Figure 1A shows sequence analysis for Case 1. The T790M mutation in EGFR is present in a recurrent liver lesion after the development of clinical gefitinib resistance. (Left) The mutation was not detected in the primary lung lesion at the time of diagnosis. (Right) Both the primary lung tumor and the recurrent liver lesion harbor the L858R gefitinib-sensitizing mutation. Of note, the L858R mutation is present in the expected ratio for a heterozygous mutation in both primary and recurrent lesions, whereas T790M is detectable at low levels compared with the wild-type allele. A polymorphism (G/A) is shown in the same tracing to demonstrate equivalent representation of the two alleles in the uncloned PCR product. Figure 1B shows sequence analysis for Case 2. The T790M mutation is present within a small minority of gefitinib-resistant cells. (Left) The T790M mutation was undetectable either in the lung primary tumor or in eight recurrent liver lesions from this case by sequencing uncloned PCR products. Heterozygosity at an adjacent polymorphism (G/A) confirms amplification of both EGFR alleles from these specimens. The heterozygous gefitinib-sensitizing mutation, L861Q, was detected at the expected ratio within the primary lung tumor as well as each of the eight recurrent liver lesions.

[0023] Figures 2A-2C show acquired resistance to gefitinib in bronchoalveolar cancer cell lines and persistent sensitivity to irreversible ERBB family inhibitors. Figure 2A shows inhibition by tyrosine kinase inhibitors of proliferation of bronchoalveolar cancer cell lines with wild-type EGFR (NCI-H1666), the activating

delE746-A750 mutation in EGFR (NCI-H1650), or two representative gefitinib-resistant subclones of NCI-H1650 (G7 and C11). The effect of the reversible inhibitor gefitinib is compared with that of the irreversible inhibitor HKI-357. Comparable results were observed with the other irreversible inhibitors. Cell numbers were measured by crystal violet staining, after culture in 5% FCS, with 100 ng/ml EGFR, at 72 h after exposure to indicated drug concentrations. Each data point represents the mean of four samples. Figure 2B shows the chemical structure of gefitinib, a reversible inhibitor of EGFR; EKB-569, an irreversible inhibitor of EGFR; and HKI-272 and HKI-357, two irreversible dual inhibitors of EGFR and ERBB2. Figure 2C shows generation of drug-resistant NCI-H1650 cells after treatment with varying concentrations of gefitinib or the irreversible ERBB inhibitor EKB-569. Colonies were stained after 12 days in culture in the presence of inhibitors.

[0024] Figures 3A-3D show persistent dependence on EGFR and ERBB2 signaling in gefitinib-resistant cells, and altered receptor trafficking. Figure 3A shows cell viability after siRNA-mediated knockdown of EGFR and ERBB2 in bronchoalveolar cell lines with wild-type EGFR (NCI-H1666), compared with cells with the activating delE746-A750 mutation in EGFR (NCI-H1650) and two gefitinib-resistant derivatives (G7 and C11). Viable cells were counted 72 h after treatment with double-stranded RNA and are shown as a fraction relative to cells treated with nonspecific siRNA, with standard deviations based on triplicate samples. Figure 3B shows inhibition of EGFR autophosphorylation (Y1068) and phosphorylation of downstream effectors AKT and MAPK (ERK) in cells treated with increasing concentrations of gefitinib or the irreversible inhibitor HKI-357, followed by a 2-h pulse with EGF. The parental cell line NCI-H1650 is compared with a representative gefitinib-resistant line, G7. Total AKT and MAPK are shown as controls; tubulin is used as loading control for total EGFR levels, which are at the lower limit of detection in these cells. Figure 3C shows altered EGFR internalization in gefitinib-resistant NCI-H1650 (G7) cells, compared with the sensitive NCI-H1650 parental cell line. Rhodamine-tagged EGF is used to label EGFR at 5 and 20 min, after addition of ligand. The increased internalization of EGFR in NCI-H1650 (G7) cells is most evident at 20 min. (Zeiss microscope, ×63 magnification). Figure 3D shows immunoblotting of internalized EGFR from NCI-H1650 parental cells and the resistant

derivative G7 after pulse labeling of cell surface proteins by biotinylation and chase over 20 min. The increased intracellular EGFR in NCI-H1650 (G7) cells is compared with the unaltered transferrin receptor (TR) internalization.

[0025] Figures 4A-4B show Effectiveness of irreversible ERBB inhibitors in suppressing the T790M EGFR mutant. Figure 4A shows comparison of gefitinib and two irreversible inhibitors, HKI-357 and HKI-272, in their ability to suppress EGFR autophosphorylation (Y1068) and phosphorylation of downstream effectors AKT and MAPK (ERK) in the NCI-H1975 bronchoalveolar cell line, harboring both a sensitizing mutation (L858R) and the resistance-associated mutation (T790M). Total EGFR, AKT, and MAPK are shown as loading controls. Figure 4B shows suppression of proliferation in NCI-H1975 cells harboring the L858R and T790M mutations by the three irreversible ERBB family inhibitors, compared with gefitinib.

[0026] Figure 5 shows the nucleotide sequence (SEQ ID NO: 2) and the amino acid sequence (SEQ ID NO: 1) of EGFR.

[0027] Figure 6 shows that like gefitinib, HKI 357 and EKB 569 (labeled "Wyeth") demonstrated increased cell killing of NSCLC cells harboring an EGFR mutation, but unlike gefitinib, clones resistant to these drugs were not readily generated in vitro and they retained their effectiveness against gefitinib-resistant clones.

DETAILED DESCRIPTION

Gefitinib and erlotinib resistant cancers

[0028] Gefitinib (compound ZD1839 developed by AstraZeneca UK Ltd.; available under the tradename IRESSA) and erlotinib (compound OSI-774 developed by Genentech, Inc. and OSI Pharmaceuticals, Inc.; available under the trade name TARCEVA) induce dramatic clinical responses in cases of non-small cell lung cancers (NSCLCs) harboring activating mutations in the EGF receptor (EGFR) (1–3), which is targeted by these competitive inhibitors of ATP binding (4, 5). The effectiveness of these tyrosine kinase inhibitors may result both from alterations in the ATP cleft associated with these mutations, which lead to enhanced inhibition of the mutant kinase by these

drugs, and from biological dependence of these cancer cells on the increased survival signals transduced by the mutant receptors, a phenomenon described as "oncogene addiction" (6, 7).

[0029] Although therapeutic responses to both gefitinib and erlotinib can persist for as long as 2–3 years, the mean duration of response in most cases of NSCLC is only 6–8 months (8–10). The mechanisms underlying acquired drug resistance are not well understood. By analogy with imatinib (GLEEVEC), which inhibits the BCR-ABL kinase involved in chronic myeloid leukemias (CMLs), the C-KIT kinase implicated in gastrointestinal stromal tumors (GISTs), and the FIP1L1-PDGFR-α kinase in idiopathic hypereosinophilic syndrome (HES), secondary kinase domain mutations can potentially suppress drug binding (11–16). However, recurrent NSCLC is not readily biopsied; hence, only limited clinical specimens are available for analysis. Recently, a single secondary mutation, T790M, within the EGFR kinase domain has been reported in three of six cases with recurrent disease after gefitinib or erlotinib therapy (17, 18). Codon 315 of *BCR-ABL*, which is analogous to *EGFR* codon 790, is frequently mutated in imatinib-resistant CML (11, 12), and mutation of the corresponding residue in *C-KIT* (codon 670) and *FIP1L1-PDGFR*-α (codon 674) is associated with imatinib-resistant GIST and HES, respectively (15, 16). Early *in vitro* modeling of resistance to EGFR inhibitors indicated that mutation of codon 790 within the wild-type receptor would similarly suppress inhibition by an EGFR tyrosine kinase inhibitor (19). Recently, transfected EGFR proteins containing activating mutations together with the T790M substitution were shown to exhibit reduced inhibition by gefitinib and erlotinib (17, 18). Although the T790M mutation seems to contribute to acquired resistance in some cases of NSCLC, the mechanisms underlying treatment failure in cases lacking secondary EGFR mutations remain unexplained.

[0030] In contrast to the cytoplasmic kinase BCR-ABL, signaling by the membrane-bound EGFR involves a complex pathway of ligand binding, receptor homodimerization, and heterodimerization with ERBB2 and other family members, followed by internalization and recycling of the ligand-bound receptor or ubiquitin-mediated receptor degradation (20). Significant EGF-dependent signaling is thought to occur during the process of internalization, which is also associated with the dissociation

of EGFR complexes at the low pH of intracellular vesicles. As such, multiple factors modulate the strength and quality of the signal transduced by the receptor, and alterations in EGFR trafficking have been closely linked with the regulation of EGF-dependent cellular responses (20).

[0031] The present invention is based on the discovery that gefitinib resistant cancers can include those wherein the T790M EGFR mutation is only present in a subset of resistant tumor cells and those wherein the T790M mutation is not observed, but increased EGFR internalization is observed. The invention is further based on the discovery that irreversible EGFR inhibitors, which covalently crosslink the receptor, are effective in inhibiting cancers with the T790M mutation and in cancers with altered EGFR trafficking that can make such cancers resistance to treatment with gefitinib and/ or erlotinib. Accordingly, the present invention provides a method of treating gefitinib and/or erlotinib resistant cancers comprising administering irreversible EGFR inhibitors.

Method of Treating a Patient

[0032] In one embodiment, the invention provides a method for treating gefitinib/erlotinib resistant cancer. The method comprises administering to a patient in need of such treatment an effective amount of certain irreversible EGFR inhibitors, including EKB-569 (4-anilinoquinoline-3-carbonitrile; Greenberger et al., 11th NCI-EORTC-AACR Symposium on New Drugs in Cancer Therapy, Amsterdam, November 7-10, 2000, abstract 388; Wyeth), HKI-357 (a derivative of 4-anilinoquinoline-3-carbonitrile; Tsou et al. J. Med. Chem. 2005, 48: 1107–1131; Wyeth) and/or HKI-272 (a derivative of 4-anilinoquinoline-3-carbonitrile; Rabindran et al., Cancer Res. 2004, 64, 3958-3965; Wyeth). In one preferred embodiment, the invention provides a method comprising administering to a patient in need of such treatment an effective amount of EKB-569. In one preferred embodiment, the invention provides a method comprising administering to a patient in need of such treatment an effective amount of HKI-357.

[0033] The treatment may also involve a combination of treatments, including, but not limited to a tyrosine kinase inhibitor in combination with other tyrosine kinase inhibitors, chemotherapy, radiation, etc..

[0034] Cancers may initially be diagnosed as gefitinib/ erlotinib sensitive or predicted to be gefitinib/ erlotinib sensitive by means of the methods described in Lynch et al., 2004; 350:2129-2139. Gefitinib/ erlotinib sensitivity may be predicted by the presence in the tumor of EGFR mutations including, for example, deletion of residues 747 (lysine) to 749 (glutamic acid) combined with a mutation in 750 (alanine), deletion of residues 747 (lysine) to 750 (alanine), substitution of arginine for leucine at residue 858, of substitution of glutamine for leucine at residue 861.

[0035] Cancers may be diagnosed as gefitinib and/or erlotinib resistant after treatment with gefitinib and/or erlotinib has commenced. Alternatively, cancers may be diagnosed as gefitinib and/or erlotinib resistant prior to initiation of treatment with such compounds. Gefitinib and/or erlotinib resistance in the tumor may occur after, e.g., 6 months or longer of gefitinib and/or erlotinib treatment. Alternatively, gefitinib and/or erlotinib resistance of the tumor may be diagnosed less than 6 months after gefitinib and/or erlotinib treatment has commenced. Diagnosis of gefitinib and/or erlotinib resistance may be accomplished by way of monitoring tumor progression during gefitinib and/or erlotinib treatment. Tumor progression may be determined by comparison of tumor status between time points after treatment has commenced or by comparison of tumor status between a time point after treatment has commenced to a time point prior to initiation of gefitinib and/or erlotinib treatment. Tumor progression may be monitored during gefitinib and/or erlotinib treatment visually, for example, by means of radiography, for example, X-ray, CT scan, or other monitoring methods known to the skilled artisan, including palpitation of the cancer or methods to monitor tumor biomarker levels. Progression of the cancer during treatment with gefitinib and/or erlotinib indicates gefitinib and/or erlotinib resistance. A rise in level of tumor biomarkers indicates tumor progression. Thus, a rise in tumor biomarker levels during treatment with gefitinib and/or erlotinib indicates gefitinib and/or erlotinib resistance. Detection of new tumors or detection of metastasis indicates tumor progression. Cessation of tumor shrinkage indicates tumor progression. Growth of the cancer is indicated by, for example, increase in tumor size, metastasis or detection of new cancer, and/or a rise in tumor biomarker levels.

[0036] The development of gefitinib and/or erlotinib resistance may be monitored by means of testing for presence of a gefitinib and/or erlotinib resistance associated mutation in circulating tumor cells obtained from the circulation, or other bodily fluid, of the subject. Presence of gefitinib and/or erlotinib resistance associated mutations in tumor cells from the subject is indicative of a gefitinib and/or erlotinib resistant tumor.

[0037] In one embodiment, the subject's tumor harbors mutations indicative of gefitinib and/or erlotinib sensitivity, yet it is resistant to gefitinib and/or erlotinib treatment. In one embodiment, the subject's tumor harbors mutations indicative gefitinib and/or erlotinib sensitivity and harbors mutations indicative of gefitinib and/or erlotinib resistance, e.g., the T790M mutation, that is, where a methione residue is substituted for the native threonine residue, in EGFR, e.g. increased EGFR internalization. In one embodiment, the subject's tumor does not harbor mutations indicative of gefitinib and/or erlotinib sensitivity and does harbor mutations indicative of gefitinib and/or erlotinib resistance, e.g., the T790M mutation in EGFR, e.g., increased EGFR internalization.

[0038] In connection with the administration of the drug, an "effective amount" indicates an amount that results in a beneficial effect for at least a statistically significant fraction of patients, such as a improvement of symptoms, a cure, a reduction in disease load, reduction in tumor mass or cell numbers, extension of life, improvement in quality of life, or other effect generally recognized as positive by medical doctors familiar with treating the particular type of disease or condition.

[0039] The effective dosage of active ingredient employed may vary depending on the particular compound employed, the mode of administration and the severity of the condition being treated. The skilled artisan is aware of the effective dose for each patient, which may vary with disease severity, individual genetic variation, or metabolic rate. However, in general, satisfactory results are obtained when the compounds of the invention are administered at a daily dosage of from about 0.5 to about 1000 mg/kg of body weight, optionally given in divided doses two to four times a day, or in sustained release form. The total daily dosage is projected to be from about 1 to 1000 mg, preferably from about 2 to 500 mg. Dosage forms suitable for internal use comprise from about 0.5 to 1000 mg of the active compound in intimate admixture with a solid or liquid pharmaceutically acceptable carrier. This dosage regimen may be adjusted to provide the

optimal therapeutic response. For example, several divided doses may be administered daily or the dose may be proportionally reduced as indicated by the exigencies of the therapeutic situation.

[0040] The route of administration may be intravenous (I.V.), intramuscular (I.M.), subcutaneous (S.C.), intradermal (I.D.), intraperitoneal (I.P.), intrathecal (I.T.), intrapleural, intrauterine, rectal, vaginal, topical, intratumor and the like. The compounds of the invention can be administered parenterally by injection or by gradual infusion over time and can be delivered by peristaltic means.

[0041] Administration may be by transmucosal or transdermal means. For transmucosal or transdermal administration, penetrants appropriate to the barrier to be permeated are used in the formulation. Such penetrants are generally known in the art, and include, for example, for transmucosal administration bile salts and fusidic acid derivatives. In addition, detergents may be used to facilitate permeation. Transmucosal administration may be through nasal sprays, for example, or using suppositories. For oral administration, the compounds of the invention are formulated into conventional oral administration forms such as capsules, tablets and tonics.

[0042] For topical administration, the pharmaceutical composition (inhibitor of kinase activity) is formulated into ointments, salves, gels, or creams, as is generally known in the art.

[0043] The therapeutic compositions of this invention, e.g. irreversible EGFR inhibitors, are conventionally administered intravenously, as by injection of a unit dose, for example. The term "unit dose" when used in reference to a therapeutic composition of the present invention refers to physically discrete units suitable as unitary dosage for the subject, each unit containing a predetermined quantity of active material calculated to produce the desired therapeutic effect in association with the required diluents; i.e., carrier, or vehicle.

[0044] The compositions are administered in a manner compatible with the dosage formulation, and in a therapeutically effective amount. The quantity to be administered and timing depends on the subject to be treated, capacity of the subject's system to utilize the active ingredient, and degree of therapeutic effect desired. Precise

amounts of active ingredient required to be administered depend on the judgment of the practitioner and are peculiar to each individual.

[0045] The therapeutic composition useful for practicing the methods of the present invention, e.g. irreversible EGFR inhibitors, are described herein. Any formulation or drug delivery system containing the active ingredients, which is suitable for the intended use, as are generally known to those of skill in the art, can be used. Suitable pharmaceutically acceptable carriers for oral, rectal, topical or parenteral (including inhaled, subcutaneous, intraperitoneal, intramuscular and intravenous) administration are known to those of skill in the art. The carrier must be pharmaceutically acceptable in the sense of being compatible with the other ingredients of the formulation and not deleterious to the recipient thereof.

[0046] As used herein, the terms "pharmaceutically acceptable", "physiologically tolerable" and grammatical variations thereof, as they refer to compositions, carriers, diluents and reagents, are used interchangeably and represent that the materials are capable of administration to or upon a mammal without the production of undesirable physiological effects.

[0047] Formulations suitable for parenteral administration conveniently include sterile aqueous preparation of the active compound which is preferably isotonic with the blood of the recipient. Thus, such formulations may conveniently contain distilled water, 5% dextrose in distilled water or saline. Useful formulations also include concentrated solutions or solids containing the compound which upon dilution with an appropriate solvent give a solution suitable for parental administration above.

[0048] For enteral administration, a compound can be incorporated into an inert carrier in discrete units such as capsules, cachets, tablets or lozenges, each containing a predetermined amount of the active compound; as a powder or granules; or a suspension or solution in an aqueous liquid or non-aqueous liquid, e.g., a syrup, an elixir, an emulsion or a draught. Suitable carriers may be starches or sugars and include lubricants, flavorings, binders, and other materials of the same nature.

[0049] A tablet may be made by compression or molding, optionally with one or more accessory ingredients. Compressed tablets may be prepared by compressing in a suitable machine the active compound in a free-flowing form, e.g., a powder or granules,

optionally mixed with accessory ingredients, e.g., binders, lubricants, inert diluents, surface active or dispersing agents. Molded tablets may be made by molding in a suitable machine, a mixture of the powdered active compound with any suitable carrier.

[0050] A syrup or suspension may be made by adding the active compound to a concentrated, aqueous solution of a sugar, e.g., sucrose, to which may also be added any accessory ingredients. Such accessory ingredients may include flavoring, an agent to retard crystallization of the sugar or an agent to increase the solubility of any other ingredient, e.g., as a polyhydric alcohol, for example, glycerol or sorbitol.

[0051] Formulations for rectal administration may be presented as a suppository with a conventional carrier, e.g., cocoa butter or Witepsol S55 (trademark of Dynamite Nobel Chemical, Germany), for a suppository base.

[0052] Formulations for oral administration may be presented with an enhancer. Orally-acceptable absorption enhancers include surfactants such as sodium lauryl sulfate, palmitoyl carnitine, Laureth-9, phosphatidylcholine, cyclodextrin and derivatives thereof; bile salts such as sodium deoxycholate, sodium taurocholate, sodium glycochlate, and sodium fusidate; chelating agents including EDTA, citric acid and salicylates; and fatty acids (e.g., oleic acid, lauric acid, acylcarnitines, mono- and diglycerides). Other oral absorption enhancers include benzalkonium chloride, benzethonium chloride, CHAPS (3-(3-cholamidopropyl)-dimethylammonio-1-propanesulfonate), Big-CHAPS (N, N-bis(3-D-gluconamidopropyl)-cholamide), chlorobutanol, octoxynol-9, benzyl alcohol, phenols, cresols, and alkyl alcohols. An especially preferred oral absorption enhancer for the present invention is sodium lauryl sulfate.

[0053] Alternatively, the compound may be administered in liposomes or microspheres (or microparticles). Methods for preparing liposomes and microspheres for administration to a patient are well known to those of skill in the art. U.S. Pat. No. 4,789,734, the contents of which are hereby incorporated by reference, describes methods for encapsulating biological materials in liposomes. Essentially, the material is dissolved in an aqueous solution, the appropriate phospholipids and lipids added, along with surfactants if required, and the material dialyzed or sonicated, as necessary. A review of known methods is provided by G. Gregoriadis, Chapter 14, "Liposomes," Drug Carriers in Biology and Medicine, pp. 287-341 (Academic Press, 1979).

[0054] Microspheres formed of polymers or proteins are well known to those skilled in the art, and can be tailored for passage through the gastrointestinal tract directly into the blood stream. Alternatively, the compound can be incorporated and the microspheres, or composite of microspheres, implanted for slow release over a period of time ranging from days to months. See, for example, U.S. Pat. Nos. 4,906,474, 4,925,673 and 3,625,214, and Jein, TIPS 19:155-157 (1998), the contents of which are hereby incorporated by reference.

[0055] In one embodiment, the tyrosine kinase inhibitor of the present invention can be formulated into a liposome or microparticle which is suitably sized to lodge in capillary beds following intravenous administration. When the liposome or microparticle is lodged in the capillary beds surrounding ischemic tissue, the agents can be administered locally to the site at which they can be most effective. Suitable liposomes for targeting ischemic tissue are generally less than about 200 nanometers and are also typically unilamellar vesicles, as disclosed, for example, in U.S. Pat. No. 5,593,688 to Baldeschweiler, entitled "Liposomal targeting of ischemic tissue," the contents of which are hereby incorporated by reference.

[0056] Preferred microparticles are those prepared from biodegradable polymers, such as polyglycolide, polylactide and copolymers thereof. Those of skill in the art can readily determine an appropriate carrier system depending on various factors, including the desired rate of drug release and the desired dosage.

[0057] In one embodiment, the formulations are administered via catheter directly to the inside of blood vessels. The administration can occur, for example, through holes in the catheter. In those embodiments wherein the active compounds have a relatively long half life (on the order of 1 day to a week or more), the formulations can be included in biodegradable polymeric hydrogels, such as those disclosed in U.S. Pat. No. 5,410,016 to Hubbell et al. These polymeric hydrogels can be delivered to the inside of a tissue lumen and the active compounds released over time as the polymer degrades. If desirable, the polymeric hydrogels can have microparticles or liposomes which include the active compound dispersed therein, providing another mechanism for the controlled release of the active compounds.

[0058] The formulations may conveniently be presented in unit dosage form and may be prepared by any of the methods well known in the art of pharmacy. All methods include the step of bringing the active compound into association with a carrier which constitutes one or more accessory ingredients. In general, the formulations are prepared by uniformly and intimately bringing the active compound into association with a liquid carrier or a finely divided solid carrier and then, if necessary, shaping the product into desired unit dosage form.

[0059] The formulations may further include one or more optional accessory ingredient(s) utilized in the art of pharmaceutical formulations, e.g., diluents, buffers, flavoring agents, binders, surface active agents, thickeners, lubricants, suspending agents, preservatives (including antioxidants) and the like.

[0060] Compounds of the present methods (i.e. irreversible EGFR inhibitors) may be presented for administration to the respiratory tract as a snuff or an aerosol or solution for a nebulizer, or as a microfine powder for insufflation, alone or in combination with an inert carrier such as lactose. In such a case the particles of active compound suitably have diameters of less than 50 microns, preferably less than 10 microns, more preferably between 2 and 5 microns.

[0061] Generally for nasal administration a mildly acid pH will be preferred. Preferably the compositions of the invention have a pH of from about 3 to 5, more preferably from about 3.5 to about 3.9 and most preferably 3.7. Adjustment of the pH is achieved by addition of an appropriate acid, such as hydrochloric acid.

[0062] The preparation of a pharmacological composition that contains active ingredients dissolved or dispersed therein is well understood in the art and need not be limited based on formulation. Typically such compositions are prepared as injectables either as liquid solutions or suspensions, however, solid forms suitable for solution, or suspensions, in liquid prior to use can also be prepared. The preparation can also be emulsified.

[0063] The active ingredient can be mixed with excipients which are pharmaceutically acceptable and compatible with the active ingredient and in amounts suitable for use in the therapeutic methods described herein. Suitable excipients are, for example, water, saline, dextrose, glycerol, ethanol or the like and combinations thereof. In

addition, if desired, the composition can contain minor amounts of auxiliary substances such as wetting or emulsifying agents, pH buffering agents and the like which enhance the effectiveness of the active ingredient.

[0064] The irreversible kinase inhibitors of the present invention can include pharmaceutically acceptable salts of the components therein. Pharmaceutically acceptable salts include the acid addition salts (formed with the free amino groups of the polypeptide) that are formed with inorganic acids such as, for example, hydrochloric or phosphoric acids, or such organic acids as acetic, tartaric, mandelic and the like. Salts formed with the free carboxyl groups can also be derived from inorganic bases such as, for example, sodium, potassium, ammonium, calcium or ferric hydroxides, and such organic bases as isopropylamine, trimethylamine, 2-ethylamino ethanol, histidine, procaine and the like.

[0065] Physiologically tolerable carriers are well known in the art. Exemplary of liquid carriers are sterile aqueous solutions that contain no materials in addition to the active ingredients and water, or contain a buffer such as sodium phosphate at physiological pH value, physiological saline or both, such as phosphate-buffered saline. Still further, aqueous carriers can contain more than one buffer salt, as well as salts such as sodium and potassium chlorides, dextrose, polyethylene glycol and other solutes.

[0066] Liquid compositions can also contain liquid phases in addition to and to the exclusion of water. Exemplary of such additional liquid phases are glycerin, vegetable oils such as cottonseed oil, and water-oil emulsions.

Definitions:

[0067] The terms "ErbB1", "epidermal growth factor receptor" and "EGFR" are used interchangeably herein and refer to native sequence EGFR as disclosed, for example, in Carpenter et al. Ann. Rev. Biochem. 56:881-914 (1987), including variants thereof (e.g. a deletion mutant EGFR as in Humphrey et al. PNAS (USA) 87:4207-4211 (1990)). erbB1 refers to the gene encoding the EGFR protein product. As used herein, the EGFR protein is disclosed as GenBank accession no. NP_005219 (SEQ ID NO: 1)

which is encoded by the erbB1 gene, GenBank accession no. NM_005228 (SEQ ID NO: 2). Nucleotide and amino acid sequences of erbB1/EGFR may be found in Figure 5.

[0068] The term "kinase activity increasing nucleic acid variance" as used herein refers to a variance (i.e. mutation) in the nucleotide sequence of a gene that results in an increased kinase activity. The increased kinase activity is a direct result of the variance in the nucleic acid and is associated with the protein for which the gene encodes.

[0069] The term "drug" or "compound" as used herein refers to a chemical entity or biological product, or combination of chemical entities or biological products, administered to a person to treat or prevent or control a disease or condition. The chemical entity or biological product is preferably, but not necessarily a low molecular weight compound, but may also be a larger compound, for example, an oligomer of nucleic acids, amino acids, or carbohydrates including without limitation proteins, oligonucleotides, ribozymes, DNAzymes, glycoproteins, siRNAs, lipoproteins, aptamers, and modifications and combinations thereof.

[0070] As used herein, the terms "effective" and "effectiveness" includes both pharmacological effectiveness and physiological safety. Pharmacological effectiveness refers to the ability of the treatment to result in a desired biological effect in the patient. Physiological safety refers to the level of toxicity, or other adverse physiological effects at the cellular, organ and/or organism level (often referred to as side-effects) resulting from administration of the treatment. "Less effective" means that the treatment results in a therapeutically significant lower level of pharmacological effectiveness and/or a therapeutically greater level of adverse physiological effects.

[0071] Nucleic acid molecules can be isolated from a particular biological sample using any of a number of procedures, which are well-known in the art, the particular isolation procedure chosen being appropriate for the particular biological sample. For example, freeze-thaw and alkaline lysis procedures can be useful for obtaining nucleic acid molecules from solid materials; heat and alkaline lysis procedures can be useful for obtaining nucleic acid molecules from urine; and proteinase K extraction can be used to obtain nucleic acid from blood (Rolff, A et al. PCR: Clinical Diagnostics and Research, Springer (1994).

[0072] As used herein, a "cancer" in a subject or patient refers to the presence of cells possessing characteristics typical of cancer-causing cells, such as uncontrolled proliferation, immortality, metastatic potential, rapid growth and proliferation rate, and certain characteristic morphological features. In some circumstances, cancer cells will be in the form of a tumor, or such cells may exist locally within an animal, or circulate in the blood stream as independent cells.

EXAMPLES

[0073] **Compounds.** Compounds used herein, including EKB-569, HK1-357, and HK1-272 as described in U.S. Pat. No. 6,002,008; Greenberger et al., Proc. 11th NCI EORTC-AACR Symposium on New Drugs in Cancer Therapy, Clinical Cancer Res. Vol. 6 Supplement, Nov. 2000, ISSN 1078-0432; in Rabindran et al., Cancer Res. 64: 3958-3965 (2004); Holbro and Hynes, Ann. Rev. Pharm. Tox. 44:195-217 (2004); and Tejpar et al., J. Clin. Oncol. ASCO Annual Meeting Proc. Vol. 22, No. 14S: 3579 (2004).

[0074] **Analysis of Recurrent NSCLC and Generation of Gefitinib-Resistant NCI-H1650 Cells.** Clinical specimens of recurrent NSCLC were obtained at autopsy after appropriate consent. The entire kinase domain of *EGFR* was sequenced after analysis of uncloned PCR products. Multiple clones of exon 20 were sequenced to examine codon 790. Mutational analysis of *EGFR* (exons 1–28), ERBB2 (exons 1–24), *PTEN* (exons 1–9), *Kras* (codons 12, 13, and 61), and *p53* (exons 5–8) in gefitinib-resistant clones as well as the parental NCI-H1650 cell line was performed by automated sequencing of individual exons and flanking intronic sequence (PCR conditions available on request) with bidirectional sequencing by using dye terminator chemistry (BIGDYE version 1.1, Applied Biosystems). Sequencing reactions were run on an ABI3100 sequencer (Applied Biosystems), and electropherograms were analyzed by using SEQUENCE NAVIGATOR and FACTURA software (Applied Biosystems).

[0075] To generate resistant subclones of NCI-H1650 cells, these were treated with ethyl methane sulfonate (EMS; 600 μg/ml), allowed to recover for 72 h, and then seeded at a density of 6×10^4 cells per 10-cm^2 dish in 20 μM gefitinib. Relative resistance

of these cells to gefitinib, compared with the irreversible inhibitors, was achieved by seeding 5×10^4 cells in six-well plates in 5% FCS and 100 ng/ml EGF (Sigma), in the presence of varying concentrations of drugs, followed after 72 h by fixing cells with 4% formaldehyde, staining with 0.1% crystal violet, and quantifying cell mass by using the Odyssey Infrared Imaging System (LI-COR Biosciences, Lincoln, NE). For small interfering RNA (siRNA) knockdown experiments, cells were transfected with double-stranded RNA oligonucleotides targeting *EGFR, ERBB2* (both SMARTpool from Dharmacon, Lafayette, CO), or nonspecific control (LRT1B), using X-treme GENE transfection reagent (Roche Applied Science). After 72 h, cells were stained with crystal violet and analyzed on the Odyssey Infrared scanner.

[0076] **Immunoblotting and Signaling Studies.** Inhibition of EGFR signaling by increasing concentrations of gefitinib or the irreversible inhibitors was determined by seeding 9×10^4 cells in 24-well plates, adding the drugs to medium containing 5% FCS for 15 min, followed by a 2-h pulse with 100 ng/ml EGF, and harvesting of lysates. Lysates were prepared in 2× gel loading buffer, sonicated, boiled, and then separated by 10% SDS/PAGE, followed by electrotransfer to polyvinylidene fluoride (PVDF) membranes, and immunoblotting. Antibodies used were phospho-EGFR Y1068 and phospho-mitogen-activated protein kinase (MAPK) (Cell Signaling Technology, Beverly, MA), phospho-AKT (BioSource International, Camarillo, CA), and total EGFR, MAPK, AKT, and tubulin (Santa Cruz Biotechnology).

[0077] **Analysis of EGFR Internalization.** To demonstrate internalization of EGFR by fluorescence microscopy, cells were grown on coverslips and incubated with 1 ng/ml recombinant human (rh) EGF (Molecular Probes, Eugene, OR) for various intervals before fixing in 4% paraformaldehyde for 10 min. Coverslips were washed in PBS and mounted with ProLong Gold antifade reagent (Molecular Probes). To quantify EGFR internalization by cell surface biotinylation, cells were grown to confluency, pretreated with cyclohexamide, incubated on ice for 1 h with 1.5 mg/ml sulfosuccinimidyl-2-(biotinamido)ethyl-1,3-dithiopropionate (sulfo-NHS-SS-biotin; Pierce), and washed with blocking buffer (50 nM NH_4CL/1 mM $MgCl_2$/0.1 mM $CaCl_2$ in PBS) to quench free

sulfo-NHS-SS-biotin, followed by several further washes with PBS. The cells were then incubated in culture medium at 37°C for various intervals to allow internalization of the biotinylated molecules, washed twice for 20 min in a glutathione solution (50 mM glutathione/75 mM NaCl/75 mM NaOH/1% BSA) on ice to strip all of the biotinyl groups from the cell surface, and then scraped and lysed in 500 μM radioimmunoprecipitation assay (RIPA) buffer (25 mM Tris·HCl, pH 7.4, with 150 mM NaCL/0.1% SDS/1% Triton X-100) supplemented with NaF, Na-orthovanadate, and protease inhibitors. Cell extracts were centrifuged, and the supernatants were incubated with streptavidin beads (Sigma) to collect the biotinylated proteins, which were then analyzed by SDS/PAGE and immunoblotting with anti-EGFR antibody (SC-03, Santa Cruz Biotechnology) or antibody against transferrin receptor (Santa Cruz Biotechnology).

[0078] **Results and Discussion**

[0079] **Analysis of Recurrent Lung Cancers with Acquired Resistance to Gefitinib.** Recurrent gefitinib-resistant NSCLC developed in two patients whose tumors had harbored an activating mutation of the EGFR kinase at the time of diagnosis and who had shown a dramatic initial clinical response to the drug (1). In both cases, progressive metastatic disease in the liver led to the patients' demises, 1–2 years after initiation of treatment. In case 1, analysis of the major liver metastasis obtained at the time of autopsy indicated persistence of the sensitizing *EGFR* mutation (L858R), as well as the presence of a newly acquired T790M mutation (Fig. 1*A*). Interestingly, analysis of uncloned PCR products showed the initial L858R mutation to be present at an abundance consistent with a heterozygous mutation that is present in all tumor cells, whereas the secondary T790M mutation was seen at approximately one-fifth the abundance of the corresponding wild-type allele. Thus, this resistance-associated mutation seems to be present in only a fraction of cells within the recurrent tumor.

[0080] Case 2 involved eight distinct recurrent metastases in the liver after the failure of gefitinib therapy. In all of these independent lesions, the sensitizing L861Q *EGFR* mutation was present at the expected ratio for a heterozygous mutation. No secondary *EGFR* mutation was detectable by analysis of uncloned PCR products from any

of these metastases. However, after subcloning of the PCR products, the T790M mutation was found to be present at very low frequency in two of the four metastatic tumors analyzed (T790M, 2 of 50 clones sequenced from lesion 1 and 1 of 56 from lesion 2), but not from two other recurrent metastases (0 of 55 clones from lesion 3 and 0 of 59 from lesion 4), or the primary tumor (0 of 75 clones) (Fig. 1*B* and Table 1). Taken together, these results are consistent with previous reports that the T790M mutation is present in some, but not all, cases of acquired gefitinib resistance (three of seven tumors; see refs. 17, 18, and 21). Furthermore, as previously noted (18), even in some cases with this resistance-associated mutation, it seems to be present in only a small fraction of tumor cells within a recurrent lesion. These observations suggest that additional mechanisms of resistance are involved in cases without a secondary *EGFR* mutation and that such mechanisms coexist with the T790M mutation in other cases.

[0081] **Generation of Gefitinib-Resistant Cell Lines with Susceptibility to Irreversible Inhibitors.** Given the excellent correlation between the clinical responsiveness of EGFR-mutant NSCLC and the enhanced gefitinib-sensitivity of NSCLC cell lines with these mutations (2, 6, 22, 23), and the limited availability of clinical specimens from relapsing patients, we modeled gefitinib resistance *in vitro*. We cultured the bronchoalveolar cancer cell line NCI-H1650, which has an in-frame deletion of the EGFR kinase (delE746-A750), in 20 μM gefitinib, either with or without prior exposure to the mutagen ethyl methane sulfonate. This cell line exhibits 100-fold increased sensitivity to gefitinib, compared with some NSCLC lines expressing wild-type EGFR (6). Whereas the vast majority of these cells are efficiently killed by 20 μM gefitinib, drug-resistant colonies were readily observed at a frequency of $\approx 10^{-5}$, irrespective of mutagen treatment. Forty-nine independent drug-resistant clones were isolated, showing an average 50-fold decrease in gefitinib sensitivity (Fig. 2*A*). All of these showed persistence of the sensitizing mutation without altered expression of EGFR, and none had acquired a secondary *EGFR* mutation or new mutations in *ERBB2, p53*, *Kras*, or *PTEN*. Gefitinib-resistant clones demonstrated comparable resistance to related inhibitors of the anilinoquinazoline class. Remarkably, however, they displayed persistent sensitivity to three inhibitors of the ERBB family (Fig. 2*A*): HKI-272 (24) and HKI-357

(compound 7f in ref. 25), which are dual inhibitors of EGFR and ERBB2 (IC_{50} values of 92 and 34 nM, respectively, for EGFR and 59 and 33 nM, respectively, for ERBB2), and EKB-569 (26), a selective inhibitor of EGFR (IC_{50} values of 39 nM for EGFR and 1.3 μM for ERBB2) (Wyeth) (Fig. 2*B*). All three drugs are irreversible inhibitors, most likely via a covalent bond with the cys773 residue within the EGFR catalytic domain or the cys805 of ERBB2. Like gefitinib, these compounds demonstrate increased killing of NSCLC cells harboring an *EGFR* mutation, compared with cells expressing wild-type receptor (Fig. 2*A*). However, in contrast to gefitinib, against which resistant clones are readily generated, even at high drug concentrations, we were unable to establish clones of cells that were resistant to the irreversible inhibitors at concentrations above 10 μM, even after ethyl methane sulfonate mutagenesis (Fig. 2*C*).

[0082] **Dependence of Gefitinib-Resistant Cells on EGFR and ERBB2 Expression.** To gain insight into the mechanisms underlying the acquisition of gefitinib resistance and the persistent sensitivity to the irreversible inhibitors, we first determined whether resistant cell lines remain dependent upon EGFR for their viability. We have previously shown that siRNA-mediated knockdown of EGFR triggers apoptosis in cells harboring mutant EGFRs, but not in those with wild-type alleles (6). Significantly, parental NCI-H1650 cells as well as their gefitinib-resistant derivatives showed comparable reduction in cell viability after transfection with siRNA targeting EGFR (Fig. 3*A*). Thus, acquisition of gefitinib-resistance does not involve EGFR-independent activation of downstream effectors. Because HKI-272 and HKI-357 target both EGFR and ERBB2, we also tested suppression of this related receptor. Knockdown of ERBB2 in NCI-H1650 and its gefitinib-resistant derivatives also caused loss of viability (Fig. 3*A*), suggesting a role for EGFR–ERBB2 heterodimers in transducing essential survival signals in tumor cells harboring *EGFR* mutations. Inhibition of EGFR alone by an irreversible inhibitor seems to be sufficient to induce apoptosis in gefitinib-resistant cells, as demonstrated by the effectiveness of EKB-569, which primarily targets EGFR (26). However, given the potentially complementary effects of targeting both EGFR and ERBB2 by using siRNA and the availability of irreversible inhibitors that target both of these family members, the potential benefit of dual inhibition warrants consideration.

[0083] We compared the ability of gefitinib and irreversible ERBB family inhibitors to suppress signaling via downstream effectors of EGFR that mediate its proliferative and survival pathways. HKI-357 was 10-fold more effective than gefitinib in suppressing EGFR autophosphorylation (measured at residue Y1068), and AKT and MAPK phosphorylation in parental NCI-H1650 cells harboring the delE746-A750 EGFR mutation (Fig. 3*B*). In a gefitinib-resistant derivative, NCI-H1650(G7), gefitinib exhibited considerably reduced efficacy in suppressing AKT phosphorylation, a key EGFR signaling effector linked to gefitinib responsiveness (6), whereas HKI-357 demonstrated persistent activity (Fig. 3*B*).

[0084] **Altered EGFR Internalization in Gefitinib-Resistant Clones.** Given the absence of secondary mutations in *EGFR* and the persistent susceptibility of gefitinib-resistant cells to siRNA-mediated suppression of EGFR, we tested whether the mechanism underlying the differential inhibition of EGFR signaling in gefitinib-resistant cells by reversible and irreversible inhibitors might be correlated with alterations in receptor trafficking, a well documented modulator of EGFR-dependent signaling (20). Indeed, analysis of EGFR trafficking in NCI-H1650-derived resistant cells demonstrated a consistent increase in EGFR internalization, compared with the parental drug-sensitive cells, as measured both by internalization of fluorescein-labeled EGF (Fig. 3*C*) and quantitation of cytoplasmic biotinylated EGFR (Fig. 3*D*). No such effect was observed with the transferrin receptor, suggesting that this did not result from a generalized alteration in all receptor processing. Although further work is required to define the precise mechanism for this alteration in EGFR trafficking, a complex process in which numerous regulatory proteins have been implicated, these results suggest that gefitinib's ability to inhibit EGFR activation is compromised in these cells, whereas the action of the irreversible inhibitors are not detectably affected.

[0085] **Inhibition of T790M EGFR Signaling and Enhanced Cell Killing by Irreversible Inhibitors.** The enhanced suppression of EGFR signaling by irreversible ERBB inhibitors raised the possibility that these drugs may also exhibit persistent activity in the context of cells harboring the T790M secondary mutation in EGFR. We therefore

tested the effect of these inhibitors on the NCI-H1975 bronchoalveolar cancer cell line, which harbors both L858R and T790M mutations in *EGFR* (18). Significantly, this cell line was derived from a patient that had not been treated with an EGFR inhibitor, indicating that this mutation is not uniquely associated with acquired drug resistance. Both HKI-357 and HKI-272 were considerably more effective than gefitinib in suppressing ligand-induced EGFR autophosphorylation and its downstream signaling, as determined by AKT and MAPK phosphorylation (Fig. 4*A*). Similarly, all three irreversible inhibitors suppressed proliferation in this cell line under conditions where it is resistant to gefitinib (Fig. 4*B*). Thus, irreversible ERBB inhibitors seem to be effective in cells harboring the T790M EGFR as well as in cells with altered trafficking of the wild-type receptor.

[0086] Our results confirm the report of T790M mutations in *EGFR* as secondary mutations that arise in previously sensitive NSCLCs harboring an activating mutation, associated with the emergence of acquired resistance (17, 18). However, this mutation is present only in a subset of cases, and even tumors that harbor the T790M mutation may contain only a small fraction of cells with this mutation. These observations imply that multiple resistance mechanisms can coexist in recurrent tumors after an initial response to gefitinib or similar reversible *EGFR* inhibitors. Moreover, these findings suggest that T790M-independent resistance mechanisms may be equally, if not more, effective than the T790M substitution itself in conferring drug resistance and may explain why recurrent tumors rarely exhibit clonality for T790M (17, 18). *In vitro* mechanisms of acquired gefitinib resistance do not involve secondary EGFR mutations at a significant frequency, but instead are correlated with altered receptor trafficking. However, it should be noted that we have not examined EGFR trafficking in all of the resistant clones that we established *in vitro*, and it remains possible that additional mechanisms may contribute to gefitinib resistance in some of the clones. Nonetheless, virtually all gefitinib-resistant clones exhibited comparable sensitivity to the irreversible ERBB inhibitors.

[0087] Our results indicate striking differences between competitive EGFR inhibitors such as gefitinib, whose effectiveness is limited by the rapid development of

drug resistance *in vitro*, and irreversible inhibitors, to which acquired resistance appears to be rare (Fig. 2*C*). We speculate that increased internalization of ligand-bound EGFR in resistant cells may be linked to dissociation of the gefitinib–EGFR complex at the low pH of intracellular vesicles. In contrast, irreversible cross-linking of the receptor would be unaffected by such alterations in receptor trafficking. Acquired resistance to gefitinib is stably maintained after passage of cells for up to 20 generations in the absence of drug, suggesting that genetic or epigenetic alterations in genes that modulate EGFR turnover may underlie this phenomenon. Because receptor trafficking cannot be readily studied by using available clinical specimens, identification of such genomic alterations may be required before clinical correlations are possible. Nonetheless, such a mechanism may contribute to *in vivo* acquired gefitinib-resistance in patients with recurrent disease who do not have secondary mutations in *EGFR*.

[0088] Irreversible ERBB inhibitors also seem to be effective in overcoming gefitinib resistance mediated by the T790M mutation, an effect that presumably results from the preservation of inhibitor binding despite alteration of this critical residue. While this work was in progress, another irreversible inhibitor of EGFR [CL-387,785, Calbiochem (27)] was shown to inhibit the kinase activity of the T790M EGFR mutant (17). The effectiveness of CL-387,785 in the context of T790M was proposed to result from the absence of a chloride at position 3 of the aniline group, which is present in gefitinib and was postulated to interfere sterically with binding to the mutant methionine at codon 790. However, EKB-569, HKI-272, and HKI-357 all have chloride moieties at that position in the aniline ring, suggesting that their shared ability to bind irreversibly to EGFR is likely to explain their effectiveness, rather than the absence of a specific steric interaction with T790M (24–26). Thus, these irreversible inhibitors may prove to be broadly effective in circumventing a variety of resistance mechanisms, in addition to the T790M mutation.

Table 1. Presence of EGFR T790M mutation at very low frequency in recurrent tumors from case 2

	No. of clones	
Tumor	**T790M mutant**	**Wild type**
Primary	0	75
Recurrent 1	2	48
Recurrent 2	1	55
Recurrent 3	0	55
Recurrent 4	0	59

[0089] Sequencing of large numbers of cloned PCR products revealed that a minority of alleles within two of four liver lesions contain the T790M mutation.

[0090] The references cited throughout the application are incorporated herein by reference in their entirety.

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CLAIMS

1. A method for treating gefitinib and/or erlotinib resistant cancer, comprising the steps of:

    a. monitoring progression of a cancer in a subject at a time point after the subject has initiated gefitinib and/or erlotinib treatment, wherein progression of the cancer is indicative of cancer that is resistant to gefitinib and/ or erlotinib treatment; and

    b. administering to the subject having a cancer that is resistant to gefitinib and/ or erlotinib treatment a pharmaceutical composition comprising an irreversible epidermal growth factor receptor (EGFR) inhibitor.

2. The method of claim 1, wherein the irreversible EGFR inhibitor is selected from the group consisting of EKB-569, HKI-272 and HKI-357.

3. The method of claim 1, wherein the irreversible EGFR inhibitor binds to cysteine 773 of EGFR (SEQ ID NO: 1).

4. The method of claim 1, wherein progression of the cancer is monitored by way of visual inspection of the cancer.

5. The method of claim 4, wherein visual inspection of the cancer is by means of X-ray, CT scan or MRI.

6. The method of claim 1, wherein the progression of the cancer is monitored by way of tumor biomarker detection.

7. The method of claim 1, wherein monitoring progression of a cancer comprises comparing the cancer at a second time point with the cancer at a first time point, wherein the second time point is after the first time point, wherein the first time point is before or after initiation of gefitinib and/ or erlotinib treatment, wherein increased growth of the cancer indicates progression of the cancer.

8. The method of claim 7, wherein at additional time points the cancer is compared with preceding time points.

9. The method of claim 1, wherein the cancer is epithelial cell cancer.

10. The method of claim 1, wherein the cancer is gastrointestinal cancer, prostate cancer, ovarian cancer, breast cancer, head and neck cancer, esophageal cancer, lung cancer, non-small cell lung cancer, cancer of the nervous system, kidney cancer, retina cancer, skin cancer, liver cancer, pancreatic cancer, genital-urinary cancer and bladder cancer.

11. A method of treating cancer, comprising the steps of:

    a. administering gefitinib and/ or erlotinib to a subject with cancer;

    b. monitoring progression of the subject's cancer; and

    c. administering to the subject an irreversible EGFR inhibitor upon indication of progression of the cancer.

12. The method of claim 11, wherein the irreversible EGFR inhibitor is selected from the group consisting of EKB-569, HKI-272 and HKI-357.

13. The method of claim 11, wherein the irreversible EGFR inhibitor binds to cysteine 773 of EGFR (SEQ ID NO: 1).

14. The method of claim 11, wherein progression of the cancer is monitored by way of visual inspection of the cancer.

15. The method of claim 14, wherein visual inspection of the cancer is by means of X-ray, CT scan or MRI.

16. The method of claim 11, wherein the progression of the cancer is monitored by way of tumor biomarker detection.

17. The method of claim 11, wherein monitoring progression of a cancer comprises comparing the cancer at a second time point with the cancer at a first time point, wherein the second time point is after the first time point, wherein the first time point

is before or after initiation of gefitinib and/ or erlotinib treatment, wherein increased growth of the cancer indicates progression of the cancer.

18. The method of claim 17, wherein at additional time points the cancer is compared with preceding time points.

19. The method of claim 11, wherein the cancer is epithelial cell cancer.

20. The method of claim 11, wherein the cancer is gastrointestinal cancer, prostate cancer, ovarian cancer, breast cancer, head and neck cancer, esophageal cancer, lung cancer, non-small cell lung cancer, cancer of the nervous system, kidney cancer, retina cancer, skin cancer, liver cancer, pancreatic cancer, genital-urinary cancer and bladder cancer.

21. The method of claim 11, wherein the irreversible EGFR inhibitor is administered simultaneously with a reversible EGFR inhibitor.

22. The method of claim 21, wherein the reversible EGFR inhibitor is gefitinib or erlotinib.

23. A method of treating cancer, comprising administering to a subject with a cancer having a mutation in EGFR (SEQ ID NO: 1), wherein the mutation is substitution of a methionine for a threonine at position 790, a pharmaceutical composition comprising an irreversible EGFR inhibitor.

24. The method of claim 23, wherein the EGFR inhibitor is selected from the group consisting of EKB-569, HKI-272 and HKI-357.

25. The method of claim 23, wherein the irreversible EGFR inhibitor bind to cysteine 773 of EGFR (SEQ ID NO: 1).

26. The method of claim 23, wherein the cancer is epithelial cell cancer.

27. The method of claim 23, wherein the cancer is gastrointestinal cancer, prostate cancer, ovarian cancer, breast cancer, head and neck cancer, esophageal cancer, lung cancer, non-small cell lung cancer, cancer of the nervous system, kidney cancer, retina cancer, skin cancer, liver cancer, pancreatic cancer, genital-urinary cancer and bladder cancer.