Afatinib (BIBW-2992): a novel dual EGFR/HER2neu inhibitor with promising activity in non-small-cell lung cancer

Lung cancer is not one disease but many diseases with specific molecular profiles and treatment alternatives. EGF receptor-activating mutations predict a high, albeit short-lived, response to reversible tyrosine kinase inhibitors (e.g., gefitinib and erlotinib). Acquired resistance mutations can result in tumor progression. Dual EGFR/HER2 irreversible inhibitors are small novel molecules that can overcome gefitinib/erlotinib resistance by potentially circumventing multiple mechanisms of acquired resistance, as shown *in vitro*. Afatinib is an irreversible inhibitor with potent phosphorylation inhibitory activity of both EGF receptor and HER2. Durable responses were observed in Phase I trials in advanced non-small-cell lung cancer at 50 mg once daily. In Phase II trials, reduction in tumor size was observed in 90% of patients. The objective response and disease control rate were 62 and 94%, respectively. Median progression-free survival was estimated at 12 months (95% CI: 10.0–19.2). The most common drug-related adverse events were diarrhea and rash/acne, 18% were grade 3 and none grade 4. LUX-Lung 1, one of two global Phase III studies, was presented in October 2010. At primary analysis (358 events), the study did not meet its primary end point to improve overall survival compared with placebo.

KEYWORDS: acquired mutations ■ activating mutations ■ afatinib ■ BIBW-2992 ■ EGF receptor ■ HER2neu ■ irreversible inhibitor

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Lung cancer is the leading cause of cancer death in the USA. Approximately 215,020 new cases (114,690 men and 100,330 women) were diagnosed and 161,840 died of lung cancer in 2008 (National Cancer Institute [NCI] 2009). The extremely high lung cancer-related mortality, demonstrates the limited efficacy of traditional cytotoxic chemotherapy in patients with this disease [1,2]. In the past few years, a number of new agents have been demonstrated to have significant activity in non-small-cell lung cancer (NSCLC). These include some new chemotherapy agents and mainly targeted agents, including antiangiogenic drugs and agents blocking the EGF receptor (EGFR) pathway. EGFR is a member of the ErbB receptor tyrosine kinase family, which includes HER2, HER3 and HER4. Recently observed patterns of oncogenic mutation of *EGFR* and *HER2* present an attractive option for targeted therapy in patients with NSCLC [3–5]. Erlotinib and gefitinib are part of a first-generation of small molecules with competitive reversible EGFR tyrosine kinase inhibitory (TKI) activity. Erlotinib and gefitinib have cytotoxic activity against lung cancer cells harboring somatic gain-of-function mutations in the intracellular kinase domain of EGFR; most commonly, small in-frame deletions in exon 19 or the L858R missense mutation in exon 21 [6]. Even when dramatic clinical responses are observed in this patient population (70–80%) [7–10], caused by alterations in the ATP cleft associated with these mutations, and biological dependence of the cancer cells on the increased survival signals transduced by the mutant receptors or 'oncogene addiction' [11,12], the average response has been demonstrated to last between 6 and 8 months (Kris *et al.*) [13] and 9.2 and 10.8 months (Mitsudomi *et al.* and Maemondo *et al.*) [14,15], before the cells develop acquired drug resistance to these reversible TKIs and relapse [16]. A specific secondary mutation in the kinase domain of the EGFR, located in exon 20, leads to a substitution of Met for Thr at position 790 (T790M) and was found responsible for rendering the cells insensitive to the TKIs [17]. Although the T790M mutation was not initially detected in untreated tumor samples, more recently, the same mutation has been reported to be coexpressed with sensitive mutations in patients never treated with EGFR TKIs, accounting for the primary resistance of the harboring cells to erlotinib and gefitinib [18]. Additional mechanisms of resistance to gefitinib and erlotinib have been reported, including focal amplification of the MET proto-oncogene, by driving ErbB3 (HER3)-dependent activation of PI3K, a pathway believed to be specific to the EGFR/ErbB family of receptors, which is detected in 22% of lung cancer specimens [19], and primary resistance caused small in-frame

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insertions in exon 20 of the kinase domains of EGFR or HER2 [20]. Multiple resistance mechanisms can coexist in recurrent tumors after an initial response to gefitinib or similar reversible EGFR inhibitors. Gefitinib-resistant clones are cross-resistant to related anilinoquinazolines [21]. These observations helped guide the search for more effective therapy against a specific subset of lung cancers, based on a need for increased therapeutic efficacy of the next generation of EGFR inhibitors. The search was based on small molecules with a broader activity against ErbB receptor tyrosine kinases, but are highly selective within the human kinome, assuring an acceptable drug safety and tolerability profile.

Irreversible inhibitors of EGFR TKI

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 [22]. In gefitinib-resistant NSCLC not containing the secondary T790M *EGFR* mutation, an increased EGFR internalization correlates with drug resistance. Irreversible inhibitors that covalently crosslink the receptor are effective in cell lines with the T790M mutation and in cells with altered EGFR trafficking [23]; raising the possibility that they may circumvent multiple mechanisms of acquired resistance to gefitinib and erlotinib [21]. To prove this hypothesis, initial *in vitro* studies generated gefitinib-resistant subclones of NCI-H1650 cells by treatment with ethyl methane sulfonate (600 µg/ml), followed by exposure to 20 µM gefitinib. Despite the resistance to gefitinib, these cells displayed persistent sensitivity to dual inhibitors of EGFR and ErbB2 (HKI-272 and -357, and EKB-569) [24–26]. 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. In contrast to first-generation reversible EGFR TKIs, even at high drug concentrations, investigators were unable to establish clones of cells that were resistant to these irreversible inhibitors at concentrations above 10 µM, even after ethyl methane sulfonate mutagenesis [21]. Interestingly, irreversible inhibitors were tenfold more effective than gefitinib in suppressing EGFR autophosphorylation, and AKT and MAPK phosphorylation in parental NCI-H1650 cells harboring a sensitive mutation (delE746-A750), as well as gefitinib-resistant clones (NCI-H1650(G7)). Furthermore, 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 [21]. Gefitinib's ability to inhibit EGFR activation is compromised in gefitinib-resistant cells, whereas the irreversible activity of inhibitors is not detectably affected, which may explain the antitumor activity of irreversible inhibitors in gefitinib-resistant tumors. Finally, the NCI-H1975 bronchoalveolar cancer cell line harbors both L858R and T790M mutations in *EGFR*. In *in vitro* experiments with this cell line, both irreversible inhibitors HKI-357 and -272 were considerably more effective than gefitinib in suppressing ligand-induced EGFR autophosphorylation and its downstream signaling, as determined by AKT and MAPK phosphorylation, and suppressed cell proliferation, under gefitinib-resistant conditions [21].

Afatinib (BIBW-2992)

Preclinical experience

Afatinib (BIBW-2992) is an anilino-quinazoline derivative, developed by Boehringer Ingelheim Corp (Ridgefield, CT, USA) to covalently bind and modify the ATP-binding site of the kinase domains of EGFR (Cys773) and HER2 (Cys805), with a functional Michael acceptor group similar to the quinoline-derived irreversible EGFR inhibitors EKB-569 and HKI-272 [27,28]. Afatinib is an oral dual receptor TKI with potent irreversible inhibitory activity on ErbB1 (EGFR/HER1) and mutated ErbB1 receptors, including the T790M variant, and *ErbB2* (*HER2*). Afatinib has potent phosphorylation inhibitory activity on both EGFR (half maximal inhibitory concentration [IC_{50}]: 0.5 nM) and HER2 (IC_{50}: 14 nM) comparing favorably to reference compounds in all cell types tested (human epidermoid carcinoma cell line A431, murine NIH-3T3 cells transfected with wild-type *HER2*, breast cancer cell line BT-474 and gastric cancer cell line NCI-N87). Afatinib effectively and selectively inhibited EGFR and HER2neu total tyrosine phosphorylation *in vitro* and tumor cell proliferation *in vivo*, in *EGFR* wild-type as well as *EGFR* and *HER2* mutants, including erlotinib-resistant isoforms. Afatinib is similar to gefitinib in potency for L858R *EGFR* (IC_{50}: 0.7 nM), but approximately 100-fold more active against the gefitinib-resistant L858R/T790M *EGFR* double mutant (IC_{50}: 99 nM). Afatinib suppresses transformation in isogenic cell-based assays, inhibits survival of cancer cell lines and induces

tumor regression in xenograft and transgenic lung cancer models, with superior activity over erlotinib [29]. Afatinib showed no activity toward A549 cells, which express wild-type *EGFR* and *HER2*, but simultaneously harbor an oncogenic *K-RAS* G12S point mutation [28]. In a xenograft model of the epidermoid carcinoma cell line, A431, expressing high levels of wild-type *EGFR* and detectable levels of HER2, afatinib administration resulted in dramatic tumor regression, whilst also downregulating EGFR and AKT phosphorylation. Similarly, xenograft tumor formation by the NCIH1975 cell line, expressing *EGFR* L858R/T790M, was effectively controlled by afatinib [30]. In *de novo EGFR* L858R/T790M-driven erlotinib-resistant lung cancer, a more disease-relevant and challenging model, afatinib induced a greater than 50% tumor reduction after 4 weeks of treatment. The addition of rapamycin, an inhibitor of the EGFR–PI3K–mTOR axis, resulted in almost complete tumor regression in six *EGFR* L858R/T790M mice within 1 week of treatment, although treatment with rapamycin alone is not effective in this particular animal model [31]. Conversely, NSCLC patients with primary resistance to first-generation EGFR inhibitors caused by the previously mentioned *KRAS* mutations [32] or acquired resistance caused by amplification of the MET protooncogene [18], would not be expected to respond to treatment with afatinib alone. However, since MET signaling activates the PI3K pathway in a HER3-dependent manner [18], it is possible that the combination of afatinib and rapamycin would also be effective in patients with resistance to first-generation inhibitors that was acquired by this mechanism.

Clinical experience

Phase I studies

To assess tolerability, pharmacokinetics (PK), pharmacodynamics and clinical activity of afatinib, an escalating schedule of once-daily afatinib for 14 days, followed by a 14-day period off medication, was explored in patients with advanced solid tumors [28]. A total of 38 patients were enrolled. Dose levels were 10, 20, 30, 45, 70, 85 and 100 mg. At 100 mg, dose-limiting toxicity (DLT; common toxicity criteria grade 3 skin rash and grade 3 diarrhea despite treatment with loperamide) occurred in two patients. In the next-highest dose of 70 mg, DLT (grade 3 fatigue and alanine aminotransferase elevation) occurred in one of six patients. An intermediate dose level of 85 mg was studied. Here, DLT occurred in two patients (grade 3 diarrhea despite treatment and grade 2 diarrhea lasting more than 7 days despite treatment). An additional 12 patients were treated with 70 mg of afatinib. Skin biopsies did not show significant changes in EGFR-associated biomarkers. No partial or complete responses were observed; stable disease lasting more than four cycles was seen in seven patients. The recommended dose for studies with afatinib for 14 days followed by 14 days off medication is 70 mg once daily. The PK was dose proportional with a terminal elimination half-life ranging between 21.3 and 27.7 h on day 1 and between 22.3 and 67.0 h on day 27; afatinib exposure decreased after food intake. In another study, afatinib PK revealed moderately fast absorption and no deviation from dose proportionality after single and multiple doses [27].

A Phase I study of continuous once-daily oral afatinib was conducted to determine safety, maximum tolerated dose, PK, food effect and preliminary antitumor efficacy in patients with advanced solid tumors. A total of 53 patients received afatinib at 10–50 mg/day [33]. Afatinib was generally well tolerated. The most common adverse effects included diarrhea, nausea, vomiting, rash and fatigue. DLTs included grade 3 rash (n = 2) and reversible dyspnea secondary to pneumonitis (n = 1). The recommended Phase II dose was 50 mg/day. Three patients with NSCLC (two with in-frame exon 19 mutation deletions) experienced confirmed partial responses (PRs) sustained for 24, 18 and 34 months. Two other patients (one with esophageal carcinoma and one with NSCLC) had nonconfirmed PRs. A patient with a PR at 10 mg/day progressed and developed symptomatic brain metastases, which subsequently regressed with an increased dose of 40 mg/day of afatinib. A further seven patients had disease stabilization lasting at least 6 months [33]. Durable responses were observed in Phase I trials of afatinib in NSCLC patients with activating *EGFR* mutations and the recommended Phase II dose was 50 mg/day.

Phase II studies

Afatinib has undergone Phase II testing in patients with NSCLC, breast and prostate cancers, head and neck carcinoma, as well as glioma. In lung cancer, Boehringer Ingelheim Corp is sponsoring the LUX-Lung 2 program, which is part of the comprehensive LUX-Lung clinical trial program, comprising over ten trials conducted across the globe. As part of the program, an open-label, single arm, two-stage Phase II study was conducted in Taiwan and the USA [101]. Patients with stage IIIB/IV adenocarcinoma of

the lung, whose tumors harbor activating mutations within exon 18–21 of the EGFR receptor, with Eastern Cooperative Oncology Group (ECOG) 0–2, who progressed or relapsed after one prior cytotoxic chemotherapy regimen, as well as chemotherapy naive patients (only in stage 2), are being treated with afatinib 50 mg or 40 mg once daily until progressive disease. The protocol was amended (17 December 2008), to a lower starting dose of afatinib, with two possible dose reductions if needed after discontinuation caused by drug-related adverse events. This study is examining effectiveness of this irreversible dual inhibitor of EGFR and HER2 kinases in patients carrying EGFR-activating mutations. The primary end point is response rate (complete response [CR] and PR) according to RECIST criteria. Secondary outcome measures include safety of afatinib, clinical benefit (CR, PR and stable disease) determined by response evaluation criteria in solid tumors (RECIST), duration of objective response (OR), time to OR, progression-free survival (PFS) time, overall survival (OS) time and PK evaluation. The study began in August 2007 and the estimated primary completion date is January 2012 (final data collection date for primary outcome measure). At the time of the first interim data report in May 2008, 174 patients (156 in Taiwan and 18 in the USA) were screened for *EGFR* mutations. Mutations were present in 41% of patients from Taiwan (n = 64) and none from the USA. A total of 27 patients (42%) were identified with *EGFR* L858R, 26 (41%) with exon 19 deletion, five (7.8%) with an exon 20 insertion, and one patient each with G863V, L861P, K860E, L861Q, G719S+S768I and G724S+S768I. PRs were seen in one patient with brain metastases, and two patients with the G719S+S768I and L861Q mutations [34,35]. At the last annual meeting of the American Society of Clinical Oncology (ASCO) in June 2010, updated data were presented. A total of 444 patients were tested for *EGFR*. L858R mutation was seen in 54 (42%), deletion 19 in 52 (40%) and other mutations in 23 (18%) patients. In this study, a patient with the T790M mutation did not respond to BIBW-2992 [36]. The last update of this trial was presented at the annual meeting of the European Society of Clinical Oncology (ESMO), in October 2010 [36]. RECIST was used to assess response at 4, 8 and 12 weeks, and at 8-weekly intervals thereafter. A total of 129 patients received at least one dose of afatinib. Among the 129 patients, the investigators reported an OR rate (ORR) of 67% (confirmed ORR of 60%), disease control rate (DCR) of 86%, median PFS of 14 months and median OS of 24 months. Comparable efficacy was observed in the first- and second-line settings. A similar confirmed ORR, DCR and median PFS wereseen in the 54 patients with L858R mutations (59%, 83%, and 16.1 months, respectively) and in 52 patients with deletion 19 mutations (69%, 93% and 13.7 months, respectively). The most common drug-related adverse events were diarrhea and rash/acne in 95 and 91% of patients, respectively, with a Common Terminology Criteria for Adverse Events (CTCAE) grade of 3 in 19 and 21% of patients, respectively [37]. Another Phase II trial in advanced (EGFR-FISH$^+$) lung cancer, is currently recruiting 70 participants in Italy [102]. This is a single-arm, nonrandomized, open-label Phase II trial exploring the ORR (CR and PR) by the RECIST criteria as the primary end point, of patients with an ECOG performance score of 0, 1 or 2, pathologically confirmed stage IIIB or IV, adeno- or broncho-alveolar carcinoma type, stratified by line of therapy (first- vs second-line treatment). The secondary end points are evaluation of safety profile and PK analysis of afatinib. Presence of *K-RAS* and *EGFR* mutation is evaluated during screening for selected patients [103]. Although beyond the scope of this article, it is worth mentioning another irreversible inhibitor, neratinib (HKI-272), which has also entered Phase I and II clinical trials at 240 mg/day. A total of 167 patients were treated. The response rate was 3% in patients carrying sensitive *EGFR* mutations and 0 for wild-type. No patient with known T790M responded. Notably, three out of the four patients with an exon 18 G719X *EGFR* mutation had a PR and the fourth had stable disease lasting 40 weeks [38,39]. A Phase II, three-arm trial included stage IIIB/IV recurrent NSCLC, stratified by *EGFR* mutation or wild-type, following erlotinib, gefitinib or chemotherapy failure [40]. The study examined 165 patients accrued (median age 60 years, 30% male, 96% performance status [PS] 0 or 1 and 64% with prior chemotherapy), the ORR was 2% (four out of 165), with a median PFS of 13.1 weeks for those previously treated with EGFR TKIs and 7.4 weeks for those with prior chemotherapy exposure.

Phase III studies

On 15 February 2008, the US FDA granted fast-track designation (FDA Modernization Act of 1997 [FDAMA]) for Boehringer Ingelheim to conduct a pivotal trial program studying afatinib (BIBW-2992) in late-stage NSCLC patients. Afatinib is the first orally administered, irreversible dual inhibitor of EGFR and HER2 to

reach Phase III development in NSCLC. The LUX-Lung trial program currently includes two Phase III trials assessing the efficacy and safety of afatinib in various NSCLC patient populations across the globe. One of the LUX-Lung 3 studies is a randomized, double-blind, multicenter, Phase IIb/III study, aimed to determine the efficacy of afatinib plus best supportive care (BSC) compared with placebo plus BSC in advanced NSCLC patients who have received previous treatment with at least one but not more than two lines of cytotoxic chemotherapy (one line must have been a platinum-containing regimen), and either gefitinib or erlotinib for a period of at least 12 weeks and then progressed [104]. The primary objective of this randomized trial was to determine the survival benefit of afatinib as a single agent (arm A) as compared with a matching placebo (arm B) in this patient population. Patients on both treatment arms receive BSC in addition to study treatment. Secondary outcome measures include PFS, OR and adverse events. The expected enrolment was 585 patients. The study start date was April 2008 and the primary completion date was July 2010 (final data collection date for primary outcome measure). The LUX-Lung 1 study was presented at the last annual meeting of the ESMO, in October 2010 [41]. A total of 585 patients were randomized between May 2008 and September 2009; 390 to the afatinib arm and 195 to the placebo arm. Patient characteristics were well balanced in both arms: median age (58 years), gender (60% were women), ethnicity (58% were East Asian), PS (92% had PS 0–1), prior treatment (81% had more than 24 weeks of prior erlotinib/gefitinib), and response on prior erlotinib/gefitinib treatment (45% had a CR/PR). At primary analysis (358 events), median OS was 10.78 months with BSC plus afatinib versus 11.96 months with BSC plus placebo, with a hazard ratio of 1.08 (95% CI: 0.86–1.35). Significant advantages favoring afatinib were seen for the secondary end points of PFS by independent review (threefold increase in median PFS from 1.1 to 3.3 months, hazard ratio: 0.38; $p < 0.0001$), confirmed DCR at 8 weeks (58 vs 19%; $p < 0.0001$) and confirmed ORR (11 vs 0.5% and 7.4 vs 0.5% by investigator and independent analyses; $p < 0.01$). Postprogression chemotherapy and EGFR TKIs were more common after placebo than afatinib (70 vs 61% and 23 vs 11%, respectively). Diarrhea (87%, grade 3: 17%) and rash/acne (78%, grade 3: 14%) were the two most common side effects of afatinib, effectively managed by supportive care/dose reduction. The study did not meet its primary end point to improve OS compared with placebo [41]. Another Phase III trial compares afatinib versus chemotherapy as first-line treatment in NSCLC with *EGFR* mutation. This study, the LUX-Lung 3 trial, is currently recruiting participants [105]. This randomized, open-label Phase III trial will be performed in patients with adenocarcinoma of the lung with tumors harboring an EGFR-activating mutation. The objectives of the trial are to compare the efficacy of single-agent afatinib, arm A, with pemetrexed/cisplatin chemotherapy, arm B, as first-line treatment for this group of patients. The primary end point is PFS and the secondary end points are OR (CR and PR), disease control (CR, PR and stable disease), OS, health-related quality of life, and PK and safety of afatinib. The estimated enrollment is 330 patients. The study start date was August 2009 and the estimated primary completion date is November 2011.

LUX-Lung 5 is a randomized study of afatinib plus weekly paclitaxel versus single-agent chemotherapy following afatinib in NSCLC patients failing erlotinib or gefitinib. This study is currently recruiting participants, and has been since 17 August 2010 [106]. The primary objective of this randomized, open-label, active-controlled, multicenter trial is to determine the efficacy of afatinib given as an add-on to chemotherapy in patients with NSCLC stage IIIb or IV progressing after afatinib monotherapy compared with chemotherapy alone in this patient population. The primary end point is OS, and the secondary outcome measures are PFS, clinical benefit, ORR (CR and PR) by RECIST 1.1, time to OR, health-related quality of life using the European Organization for Research and Treatment of Cancer (EORTC) QLQ-LC13, EQ-5D and QLQ C30 questionnaires, and safety according to US NCI Common terminology Criteria for Adverse Events (US NCI CTCAE) Version 3.0. The estimated enrolment is 900 patients. The study start date was February 2010 and the estimated primary completion date is March 2012 (final data collection date for primary outcome measure).

If afatinib (BIBW-2992) is approved by the FDA, Boehringer Ingelheim will market the compound under the trade name TOVOK™.

Afatinib (BIBW-2992) in tumors with *HER2neu* mutations

HER2 mutations are found in 2–4% of lung adenocarcinomas and, similar to *EGFR* mutations, are more common in females, nonsmokers and patients with an Asian background. An exploratory Phase II study in demographically

and genetically selected NSCLC is being conducted. Patients with stage IIIB/IV lung adenocarcinoma who have never smoked or are light ex-smokers, and whose tumors harbor *EGFR* or *HER2* mutations, or are demonstrated by FISH analysis to overexpress *EGFR*, are eligible. Patients received 50 mg afatinib daily until disease progression. The primary end point is response rate. As of August 2009, three patients with a *HER2* mutation in exon 20 have been included. All three patients are female nonsmokers with stage III/IV adenocarcinoma of the lung and failed chemotherapy (up to five lines). A preliminary analysis shows significant improvement in patients' symptoms and PS, as well as tumor size reduction amounting to PR in all three patients. Diarrhea and skin rash were the prominent adverse events. This is the first report of the use of afatinib in pretreated patients with NSCLC and activating *HER2* mutations in exon 20. This mutation characterizes a subgroup of NSCLC dependent on the HER2 pathway for survival, making afatinib, an irreversible inhibitor of EGFR/HER2, a potential new treatment option for these patients [42].

Conclusion

Contrary to common misconception, lung cancer of the non-small-cell type is not just one disease. Subtypes of NSCLC have recently been characterized by molecular parameters. The molecular make-up of certain lung cancers make them particularly sensitive to inhibitors of tyrosine kinase activity in the intracellular domain of the EGFR. The two so-called reversible inhibitors in the market are gefitinib and erlotinib. Despite an overall initial response of approximately 70%, secondary resistant mutations in the cancer cells (T790M accounts for approximately 50%) lead to unresponsiveness to gefitinib and erlotinib after an average of 8.0–10.8 months. Rebiopsy is highly recommended to show new mutations responsible for the acquired resistance of tumors, especially to guide treatment decisions as new agents become available. Investigators have recently developed new small molecules that bind irreversibly to the tyrosine kinase of the receptor, overcoming resistance *in vitro*, with potential significant clinical benefit. Afatinib is one such compound as it has proven to be safe and have durable antitumor activity. LUX-Lung 1, a recently presented Phase III study (October 2010), did not meet its primary end point to improve OS, even when significant advantages favoring afatinib were seen for PFS, DCR and ORR [41].

Future perspective

Cancer is an extremely complex molecular condition. In lung cancer, genes encoding for growth factors/growth factor receptors (e.g., *EGF*/*EGFR* and *VEGF*/*VEGFR*), modulators of cell growth response (e.g., *K-RAS* and BRCA1) and enzymes involved in nucleotide excision repair pathways (e.g., ERCC1 and RRM1) have prognostic and predictive value of response and survival with certain therapeutic agents. EGFR is overexpressed in 40–80% of NSCLC patients and 10–20% carry somatic mutations of the receptor's tyrosine kinase domain, which predict a 65–81% response rate and 96% DCR to the EGFR TKIs erlotinib and gefitinib, with a median OS of 33 months. However, the response is short lived (average: 8.0–10.8 months), at which point cancer cells develop multiple acquired mechanisms of resistance, including specific new mutations. It would be naive to expect to win the battle against cancer by targeting just one molecule in the immensely complex molecular machinery of the cancer cell, made even more complex under natural genetic pressure and added genetic abnormalities associated with treatment. New targeted approaches in cancer management aim at blocking the signaling translational pathway at various key checkpoints downstream from the surface receptor or key molecular players, in two or more pathways, in a concurrent or sequential fashion. BIBW-2992 is a novel molecule with multiple molecular targets, which may account for its broader anticancer activity when compared with the first-generation EGFR TKIs. However, the positive data presented in this article should not be taken as the culmination but the beginning of a long and arduous process of understanding many current unknowns. It is possible that, in the near future, BIBW-2992 may become part of a rational combination of targeted agents that not only block a few target molecules, but also inhibit the whole cancer machinery by strategic targeting of the complex molecular network responsible for the cancer phenotype.

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Executive summary

- Erlotinib and gefitinib are reversible EGF receptor (EGFR) tyrosine kinase inhibitors with cytotoxic activity against lung cancer cells harboring somatic mutations in the kinase domain of EGFR. Even when these two drugs produce initial dramatic clinical responses, cells develop acquired drug resistance caused by new mutations.
- Irreversible inhibitors are effective in cell lines resistant to EGFR tyrosine kinase (erlotinib/gefitinib), raising the possibility that they may circumvent multiple mechanisms of acquired resistance. BIBW-2992 is an oral dual receptor tyrosine kinase inhibitor with potent irreversible inhibitory activity on ErbB1 (EGFR/HER1) and mutated ErbB1 receptors including the T790M variant, as well as ErbB2 (HER2).
- In Phase I/II, the clinical activity of 50 mg/day BIBW-2992 was explored in lung, breast, prostate and head and neck cancer, as well as glioma. In lung cancer, 129 patients were treated with BIBW-2992, and had a objective response and disease control rate of 62 and 94%, respectively, and median progression-free survival estimated at 12 months. The most common adverse effects included diarrhea, nausea, vomiting, rash and fatigue.
- In February 2008, the US FDA granted fast-track designation to Boehringer Ingelheim to conduct pivotal Phase III studies in advanced non-small-cell lung cancer patients failing erlotinib or gefitinib, or as first-line treatment versus chemotherapy in tumors harboring *EGFR* mutations.
- If BIBW-2992 is approved by the FDA, Boehringer Ingelheim will market the compound under the trade name TOVOK™.

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