

Abemaciclib in Combination with Single-Agent Options in Patients with Stage IV Non-Small Cell Lung Cancer: A Phase Ib Study



Edward S. Kim¹, Karen Kelly², Luis G. Paz-Ares³, Pilar Garrido⁴, Shadia Jalal⁵, Daruka Mahadevan⁶, Martin Gutierrez⁷, Mariano Provencio⁸, Eric Schaefer⁹, Monte Shaheen¹⁰, Erica L. Johnston¹¹, P. Kellie Turner¹¹, Siva Rama Prasad Kambhampati¹¹, Richard Beckmann¹¹, Anwar Hossain¹¹, William J. John¹¹, and Jonathan W. Goldman¹²

Abstract

Purpose: Abemaciclib, a dual inhibitor of cyclin-dependent kinases 4 and 6, has demonstrated preclinical activity in non-small cell lung cancer (NSCLC). A multicenter, nonrandomized, open-label phase Ib study was conducted to test safety, MTD, pharmacokinetics, and preliminary antitumor activity of abemaciclib in combination with other therapies for treatment in patients with metastatic NSCLC.

Patients and Methods: An initial dose escalation phase was used to determine the MTD of twice-daily oral abemaciclib (150, 200 mg) plus pemetrexed, gemcitabine, or ramucirumab, followed by an expansion phase for each drug combination. Pemetrexed and gemcitabine were administered according to label. The abemaciclib plus ramucirumab study examined two dosing schedules.

Results: The three study parts enrolled 86 patients; all received ≥ 1 dose of combination therapy. Across arms, the most common treatment-emergent adverse events were fatigue,

diarrhea, neutropenia, decreased appetite, and nausea. The trial did not identify an abemaciclib MTD for the combination with pemetrexed or gemcitabine but did so for the combination of abemaciclib with days 1 and 8 ramucirumab (8 mg/kg). Plasma sample analysis showed that abemaciclib did not influence the pharmacokinetics of the combination agents and the combination agents did not affect abemaciclib exposure. The disease control rate was 57% for patients treated with abemaciclib-pemetrexed, 25% for abemaciclib-gemcitabine, and 54% for abemaciclib-ramucirumab. Median progression-free survival was 5.55, 1.58, and 4.83 months, respectively.

Conclusions: Abemaciclib demonstrated an acceptable safety profile when dosed on a continuous twice-daily schedule in combination with pemetrexed, gemcitabine, or ramucirumab. Abemaciclib exposures remained consistent with those observed in single-agent studies. *Clin Cancer Res*; 24(22):5543–51. ©2018 AACR.

¹Levine Cancer Institute, Atrium Health, Charlotte, North Carolina. ²University of California, Davis, Comprehensive Cancer Center, Sacramento, California. ³Servicio de Oncología Médica, University Hospital Doce de Octubre, CNIO, Complutense University and CiberOnc, Madrid, Spain. ⁴Hospital Universitario Ramon y Cajal, IRYCIS, Universidad de Alcalá, CiberOnc, Madrid, Spain. ⁵Indiana University School of Medicine, Indianapolis, Indiana. ⁶University of Arizona Cancer Center, Tucson, Arizona. ⁷Hackensack University Medical Center, Hackensack, New Jersey. ⁸Servicio de Oncología Médica, Hospital Universitario Puerta de Hierro, Madrid, Spain. ⁹Highlands Oncology Group, Fayetteville, Arkansas. ¹⁰University of Arizona, Department of Medicine and Cancer Center, Tucson, Arizona. ¹¹Eli Lilly and Company, Indianapolis, Indiana. ¹²University of California at Los Angeles, Los Angeles, California.

Note: Supplementary data for this article are available at Clinical Cancer Research Online (<http://clincancerres.aacrjournals.org/>).

Current affiliation for S.R.P. Kambhampati: PK/PD and Pharmacometrics, Akros Pharma Inc., Princeton, New Jersey; and current affiliation for W.J. John, MedPace, Cincinnati, Ohio.

Corresponding Author: Edward S. Kim, Solid Tumor Oncology and Investigational Therapeutics, Levine Cancer Institute, Atrium Health, 1021 Morehead Medical Drive, Suite 3100, Charlotte, NC 28204. Phone: 980-442-3105; Fax: 980-442-3101; E-mail: Edward.Kim@carolinashalthcare.org

doi: 10.1158/1078-0432.CCR-18-0651

©2018 American Association for Cancer Research.

Introduction

Lung cancer is the most common cancer worldwide and the leading cause of cancer-related mortality (1). Non-small cell lung cancer (NSCLC) accounts for >80% of all lung cancer cases, with most patients initially diagnosed with advanced or metastatic disease (2).

Platinum-based doublets are the standard first-line therapy for NSCLC in unselected patients; and in appropriate patients, these may be combined with bevacizumab, necitumumab, or pembrolizumab (3–6). Patients with sensitizing mutations of EGFR or BRAF, or ALK or ROS-1 gene rearrangements are candidates for first-line therapy with targeted oral kinase inhibitors (2).

Unfortunately, not all patients respond to first-line therapy and even patients who initially respond will likely relapse. Many patients are candidates for second-line and eventually third-line therapy. Available second-line treatment options in unselected patients include: docetaxel (with or without ramucirumab, or nintedanib in the European Union), and pemetrexed or gemcitabine if not previously used (2, 7–11). In addition, immune checkpoint inhibitors may be used following disease progression on or after platinum-based chemotherapy: pembrolizumab is indicated for selected patients with PD-L1 expression, and nivolumab and atezolizumab in unselected patients (12–14).

Translational Relevance

Despite advances in prolonging survival of patients with metastatic NSCLC, treatment options after progression on second-line treatment remain an area of significant unmet medical need. Pemetrexed, gemcitabine, and ramucirumab are indicated for advanced NSCLC treatment. The addition of abemaciclib to single-agent chemotherapy or antiangiogenic therapy already approved in NSCLC may achieve additional clinical benefit. Preclinical studies in NSCLC models indicated potential additive benefit for the combination of single-agent treatments with abemaciclib. The JPBA phase I study demonstrated abemaciclib monotherapy activity in NSCLC, and recently, abemaciclib received FDA approval as a single agent or in combination with endocrine therapy for breast cancer. The objective of the JPBJ phase Ib study was to identify a tolerable abemaciclib dose, characterize its pharmacokinetics, and evaluate its antitumor activity when combined with single-agent chemotherapy or antiangiogenic therapy for the treatment of metastatic NSCLC. These results have potential as a foundation for future clinical development.

Despite these advances in prolonging survival of patients with metastatic NSCLC, after progression on second-line treatment, there are few options. Third-line treatment continues to be challenging, and subsequent treatment options for patients with metastatic NSCLC remains an area of significant unmet medical need.

Because cell-cycle dysregulation occurs in >90% of lung cancers (15), disrupting the cell proliferation machinery may control the growth of advanced NSCLC. During the cell cycle, the G₁ restriction point controls entry into S-phase (16). Cyclin-dependent kinases 4 and 6 (CDK4 and CDK6) form a complex with D-type cyclins to advance the cell cycle through the G₁ restriction point through phosphorylation of the Rb tumor suppressor protein (17). Inhibiting CDK4 and CDK6 prevents cell-cycle progression, halting tumor growth and promoting senescence.

Abemaciclib is a selective and potent small-molecule inhibitor of CDK4 and CDK6 with broad antitumor activity in preclinical models, acceptable physical and pharmacokinetic properties, and acceptable toxicity profile in nonclinical species (18, 19). Preclinical data showed that *KRAS*-mutant NSCLC xenograft models (NCI-H2122, NCI-H358, and NCI-H441) had greater sensitivity to abemaciclib compared with models expressing a wild-type *KRAS* gene (NCI-H1975 and NCI-H1650; ref. 20). In addition, preclinical studies conducted in *KRAS*-mutant NSCLC models (NCI-H441 and NCI-H2122) indicated potential additivity when agents such as pemetrexed, gemcitabine, or DC101 (a mouse surrogate of ramucirumab) were combined with abemaciclib. In these studies, the combination therapies demonstrated greater tumor growth inhibition as well as longer duration of growth inhibition following treatment cessation compared with abemaciclib single-agent therapy (21).

In the JPBA phase I study, single-agent abemaciclib showed acceptable safety/tolerability as well as early evidence of clinical activity in multiple tumor types, including patients with heavily pretreated metastatic NSCLC (20). Fatigue was the dose-limiting toxicity across all tumor types. The most common treatment-

emergent adverse events (TEAE) were gastrointestinal and hematopoietic and were manageable with dose adjustments and supportive care. The disease control rate (DCR) among abemaciclib-treated patients was 49% (33/68 patients); 2 patients achieved partial responses. The DCR was greater in the *KRAS*-mutant population (55%) compared with that in the *KRAS* wild-type population (39%).

On the basis of preclinical and clinical data, we conducted a multicenter phase Ib clinical study to test the safety and tolerability of oral abemaciclib combination therapy in patients with metastatic NSCLC. The secondary objectives of the study included determination of the pharmacokinetic profile for each combination therapy and assessment of antitumor activity.

Patients and Methods

A multicenter, nonrandomized, open-label phase Ib trial enrolled patients previously treated for advanced/metastatic NSCLC. The study comprised multiple study parts, each with an initial dose escalation phase to determine the MTD of abemaciclib plus pemetrexed (part A), gemcitabine (part B), or ramucirumab (part C), followed by an expansion phase for each study part. Part C also included investigation of an alternative ramucirumab dosing schedule. Two additional parts of the study, abemaciclib in combination with LY3023414 (PI3K/mTOR dual inhibitor) and pembrolizumab, have not been concluded and will be reported separately.

This study was designed by the sponsor and was conducted in accordance with the Declaration of Helsinki ethical principles and International Conference on Harmonisation Guidelines for Good Clinical Practice. Site-specific institutional review boards or ethics committees approved the study protocol and amendments. All patients provided written informed consent. The study is registered at www.ClinicalTrials.gov (NCT02079636).

Patients

Key eligibility criteria included previously treated advanced/metastatic NSCLC, age ≥ 18 years, Eastern Cooperative Oncology Group performance status ≤ 1 , and adequate hematologic and end organ function. Eligibility was not restricted on the basis of molecular features; however, all patients with EGFR-activating mutations or ALK alterations should have progressed on or after an EGFR or ALK tyrosine kinase inhibitor prior to enrollment.

Part A required nonsquamous histology and one to three prior therapies, including one platinum-based chemotherapy for advanced/metastatic NSCLC. Pemetrexed received as first-line or maintenance therapy must have been completed ≥ 3 months prior to study entry. Part B allowed any histologic subtype and required one to three prior therapies for advanced/metastatic NSCLC. Part C allowed any histologic subtype and required two to three prior therapies for advanced/metastatic NSCLC. Study allowed patients with measurable or nonmeasurable disease as defined by the Response Evaluation Criteria in Solid Tumors v1.1. The online appendix lists eligibility requirements.

Treatments and MTD determination

Supplementary Table S1 (online appendix) outlines treatments and dose escalation scheme. During the dose escalation phase, cohorts of 3 to 6 patients enrolled at each of the planned dose levels. Abemaciclib was administered orally every 12 hours (Q12H) on days 1 through 21 of a 21-day cycle at 150 or 200 mg (the established single-agent MTD) until disease progression

or other study discontinuation criteria were met. Pemetrexed (part A) and gemcitabine (part B) were administered according to label: day 1 for pemetrexed, days 1 and 8 for gemcitabine. Ramucirumab (part C) was administered on two different schedules on day 1 or on days 1 and 8 of a 21-day cycle. The ramucirumab days 1 and 8 regimen was developed on the basis of pharmacokinetic simulations with the expectation to produce higher trough concentrations relative to the standard dosing regimen (22). Dose adjustments (omission and reduction) were permitted for each drug for specific toxicities (see online appendix for details). Patients discontinued from study treatment upon progression, unacceptable toxicity, or decision by the patient, physician, or sponsor. Post-study treatment evaluation occurred 30 ± 7 days from the last dose of study drug.

Safety assessments guided the dose escalation phase during the first 21 days of treatment for all patients in each cohort. If no patient experienced a dose-limiting toxicity (DLT), dose escalation occurred to the next prespecified dose level. If one of three patients at any cohort experienced a DLT, then three additional patients were enrolled at that dose level. If a DLT was observed in ≥ 2 out of a maximum of 6 patients at any given dose, dose escalation ceased, and either the previous dose was declared the MTD for the combination therapy or additional patients were treated at the previous dose level to ensure < 2 DLTs of 6 patients occurred at that dose level. If more than 2 of 6 patients experienced a DLT at 150 mg Q12H, then the dose of abemaciclib was to be deescalated to 100 mg Q12H. After the MTD for each combination therapy was identified in each study part in the dose escalation phase, each study part enrolled 12 additional patients for the confirmation phase of the study. Part C (ramucirumab) included a second dose escalation and a 6-patient confirmation cohort to evaluate an alternate dosing schedule for ramucirumab.

A DLT was defined as an adverse event (AE) occurring during cycle 1 of the dose escalation phase that was possibly related to either abemaciclib or the combination therapy and fulfilled any of the following criteria: grade 3 or 4 nausea, vomiting, diarrhea, or electrolyte disturbance persisting > 2 days despite intervention, any other grade 3 or 4 nonhematologic toxicity, grade 4 hematologic toxicity that lasted longer than 5 days, grade 3 or 4 thrombocytopenia with evidence of bleeding, or febrile neutropenia. A DLT-equivalent toxicity (DET) was defined as an AE that would have met the criteria for DLT if it had occurred during cycle 1 of the dose escalation phase, but that occurred in a later cycle or during any cycle of the dose confirmation phase.

Assessments

Safety was assessed by AEs, DLTs, central laboratory tests, and local electrocardiograms. Adverse events were assessed for severity using the National Cancer Institute Common Terminology Criteria for Adverse Events (version 4.0) (23). Radiologic tumor assessments were performed locally at baseline and then every 6 weeks thereafter until evidence of disease progression. Tumor response was assessed using Response Evaluation Criteria in Solid Tumors v1.1 (24).

Pharmacokinetic samples were collected for all patients to measure concentrations of abemaciclib and its metabolites (LSN2839567, LSN3106729, and LSN3106726). Separate blood samples were collected to measure concentrations of pemetrexed (part A), gemcitabine plus its metabolite 2',2'-difluorodeoxyuridine (dFdU) (part B), and ramucirumab (part C).

Pharmacokinetic samples were collected at predose, immediately postdose (cycle 1, day 1 only), and at 1, 2, 4, 6, 8, 10 hours postdose of abemaciclib on cycle 1, day 1 and on cycle 2, day 1 for abemaciclib and combination agents. Additional samples were collected at predose of cycle 1, day 8 (for abemaciclib and its metabolites, gemcitabine plus its metabolite, and ramucirumab) and cycle 1, day 15 (for abemaciclib and its metabolites). Pharmacokinetic analyses were conducted on patients who had received at least 1 dose of study drug and had adequate samples collected. Plasma concentrations of abemaciclib and its metabolites were assayed at Q2 Solutions. Plasma samples were analyzed for pemetrexed and gemcitabine and its metabolite at BASi. Serum concentrations of ramucirumab were assayed at Intertek Pharmaceutical Services. Pharmacokinetic parameter estimates were computed for abemaciclib, its metabolites, and whenever possible, for pemetrexed, gemcitabine, and ramucirumab. Pharmacokinetic parameters were computed by standard noncompartmental methods using WinNonlin (Professional Edition). The primary parameters for analysis were maximum concentration (C_{max}) and area under the concentration–time curve from time zero to the last observation ($AUC_{0-tlast}$).

Statistical methods

All patients who had at least 1 dose of study therapy were included in the analyses. Data were summarized by study part and dose group, as appropriate. For continuous variables, summary statistics included mean, median, SD, and range. Categorical endpoints such as baseline characteristics, safety, and tumor response were summarized as frequency and percentages. Progression-free survival (PFS) was analyzed using Kaplan–Meier methodology (25). Statistical Analyses System (SAS) V9 was used to analyze the data.

Results

From April 2014 through March 2016, 10 centers in the United States and Spain enrolled 86 patients with stage IV NSCLC in parts A, B, or C of the study based on prior therapy or histology. All patients were evaluable for safety and efficacy assessment. At the time of data cutoff (August 24, 2016), all patients except five (all on part C) had discontinued study treatment (Supplementary Table S2, online appendix). The median age was 64–66 years across study parts (range: 43–83 years), with a median of 2 prior lines of therapy for advanced/metastatic disease (Table 1).

All patients received abemaciclib (150 or 200 mg, twice daily) while on study in combination with either pemetrexed (part A), gemcitabine (part B), or ramucirumab (part C) on a 21-day cycle. Median number of cycles was 1.5–3.0 and range was 1–30 (Supplementary Table S3, online appendix). Abemaciclib dose reductions occurred in 11 of 23 (48%) patients in part A, 8 of 24 (33%) patients in part B, and 14 of 39 (36%) patients in part C. Dose omissions occurred in 15 patients in both parts A and B (65% and 63%, respectively), and in 21 patients (54%) in part C. The relative dose intensity of abemaciclib was 75%–93% among the various treatment and dosage groups (Supplementary Table S3, online appendix).

Dose escalation and MTD determination

Part A. The MTD was not reached for the abemaciclib–pemetrexed combination. At the 150-mg abemaciclib dose level, eight patients were enrolled; two of the initial three patients were

Table 1. Demographic profile of study populations

	Part A Abemaciclib +Pemetrexed (n = 23)	Part B Abemaciclib +Gemcitabine (n = 24)	Part C Abemaciclib +Ramucirumab (n = 39)
Age			
Median (range), years	64 (43–83)	66 (43–80)	66 (43–82)
≥65 years, n (%)	11 (48)	13 (54)	16 (62)
Male, n (%)	14 (61)	13 (54)	23 (59)
Race, n (%)			
American Indian	0	2 (8)	0
Asian	1 (4)	2 (8)	1 (3)
Black	1 (4)	1 (4)	0
White	21 (91)	19 (79)	38 (97)
Country, n (%)			
Spain	9 (39)	6 (25)	13 (33)
United States	14 (61)	18 (75)	26 (67)
ECOG PS, n (%)			
0	11 (48)	12 (50)	10 (26)
1	12 (52)	12 (50)	29 (74)
Histology, n (%)			
Adenocarcinoma ^a	21 (91)	19 (79)	28 (76)
Large cell carcinoma	0	1 (4)	1 (3)
Squamous ^b	0	3 (13)	6 (16)
Lung, other/not otherwise specified ^c	2 (9)	1 (4)	2 (5)
Median duration of disease from initial diagnosis (range), months	16 (4–50)	19 (6–119)	19 (6–102)
Prior systemic therapies, median (range)			
Any intent	2 (1–5)	2.5 (1–5)	2 (1–6)
Advanced/metastatic	2 (1–3)	2 (1–4)	2 (1–6)

^aTwo patients had incomplete data for part C histology. Percentages are based on the number of patients with data.

^bIncludes squamous and adenosquamous (predominantly squamous). Only patients with nonsquamous histology were eligible for part A.

^cIncludes bronchioalveolar, adenosquamous (not specified), and lung-not otherwise specified.

deemed not evaluable and replaced. One patient experienced DLTs at 150 mg abemaciclib. No other DLTs occurred in part A at the 150-mg abemaciclib dose level (Table 2). At the 200-mg abemaciclib dose level, no DLTs were observed during cycle 1; one DET of grade 3 febrile neutropenia occurred during cycle 2. During cycle 2 of the 200-mg abemaciclib confirmation phase, one patient experienced grade 3 febrile neutropenia, and two patients experienced grade 4 neutropenia lasting longer than 5 days.

Part B. The MTD was not reached for the abemaciclib–gemcitabine combination. At the 150-mg abemaciclib dose level, no DLTs were reported (Table 2). At the 200-mg abemaciclib dose level, one DLT of grade 3 fatigue occurred and four DETs, including grade 3 fatigue, grade 3 diarrhea, and two patients with grade 3 infections (grade 4 sepsis; grade 4 neutropenia/febrile neutropenia).

Part C. Part C evaluated two different dose schedules for ramucirumab. The first part C dosing schedule evaluated abemaciclib 150 or 200 mg twice daily in combination with ramucirumab 10 mg/kg on day 1 of a 21-day schedule (hereafter referred to as day 1 regimen). The second dosing schedule evaluated abemaciclib 150 mg twice daily in combination with ramucirumab 8 or 10 mg/kg on days 1 and 8 of a 21-day schedule (hereafter referred to as day 1, 8 regimen).

The MTD was not reached for the day 1 regimen. At the 150-mg abemaciclib dose level (ramucirumab 10 mg/kg day 1), 4 patients enrolled; one of the initial three patients was not evaluable and replaced. No DLTs were reported and one DET of grade 3 hyponatremia occurred during cycle 9. At the 200-mg abemaciclib dose level (ramucirumab 10 mg/kg day 1), two DLTs were reported in a single patient, grade 4 neutropenia and

grade 4 leukopenia, and therefore the MTD was not achieved. DETs included grade 3 diarrhea, grade 4 hypokalemia, and grade 3 stomatitis (Table 2).

For the day 1, 8 regimen, 12 patients enrolled at the 8 mg/kg ramucirumab days 1, 8 dose level and 4 patients at the 10 mg/kg ramucirumab days 1, 8 dose level. At the 8 mg/kg days 1, 8 dose level, 1 DLT of grade 3 stomatitis and 2 DETs of grade 3 fatigue occurred. At the 10 mg/kg days 1, 8 dose level, 4 DLTs occurred (3 patients), 1 DLT each of grade 4 embolism, and grade 3 myocardial infarction, and two DLTs of grade 3 fatigue. Thus, the MTD declared for part C second dosing schedule was abemaciclib 150 mg twice daily and ramucirumab 8 mg/kg on days 1 and 8 of a 21-day cycle.

Safety

Part A. Among patients receiving the combination of abemaciclib and pemetrexed, the most common nonhematologic TEAEs (any grade) were fatigue (74%), diarrhea (78%), decreased appetite (57%), nausea (48%), dyspnea (39%), increased blood creatinine (39%), stomatitis (30%), and vomiting (22%; Table 3). The most common hematologic TEAEs (any grade) were neutropenia (65%), anemia (74%), thrombocytopenia (44%), and leukopenia (30%). All-cause grade 3–4 TEAEs in ≥10% of patients were neutropenia (65%), anemia (26%), leukopenia (22%), dyspnea (22%), and thrombocytopenia (17%). Supplementary Table S3 explains dose reduction information for part A.

Part B. Abemaciclib plus gemcitabine yielded a similar pattern of TEAEs as observed in part A. The most common nonhematologic TEAEs (any grade) were fatigue (75%), nausea (67%), diarrhea (58%), decreased appetite (33%), vomiting (29%), dyspnea (21%), and increased blood creatinine (21%; Table 3). The most common hematologic TEAEs (any grade) were neutropenia

Table 2. DLTs and DLT-equivalent toxicities

Abemaciclib dose (mg)	Patients treated, <i>n</i>	Patients with DLT or DET, <i>n</i>	Cohort ^a	DLT or DET ^b	Cycle
Part A: Abemaciclib + Pemetrexed					
150 mg Q12H	8	1	Escalation	Acute kidney injury, Gr 3; blood creatinine increased, Gr 3; fatigue, Gr 3	1
200 mg Q12H	15	4	Escalation	Febrile neutropenia, Gr 3	2
			Confirmation	Febrile neutropenia, Gr 3	1
			Confirmation	Neutropenia, Gr 4	2
			Confirmation	Neutropenia, Gr 4	2
Part B: Abemaciclib + Gemcitabine					
150 mg Q12H	3	0	-	None	-
200 mg Q12H	21	5	Escalation	Fatigue, Gr 3	1
			Confirmation	Fatigue, Gr 3	1
			Confirmation	Diarrhea, Gr 3	1
			Confirmation	Scrotal infection, Gr 3	1
			Confirmation	Neutropenia, Gr 4	2
Part C: Abemaciclib + Ramucirumab					
150 mg Q12H + Ram 10 mg/kg day 1	4	1	Escalation	Hyponatremia, Gr 3	9
200 mg Q12H + Ram 10 mg/kg day 1	19	3	Escalation	Leukopenia, Gr 4	1
			Escalation	Neutropenia, Gr 4	
			Escalation	Diarrhea, Gr 3	2,3
			Confirmation	Hypokalemia, Gr 4	3
150 mg Q12H + Ram 8 mg/kg days 1 and 8	12	2	Confirmation	Stomatitis, Gr 3	1
			Escalation	Stomatitis, Gr 3	1
			Confirmation	Fatigue, Gr 3	2
150 mg Q12H + Ram 10 mg/kg days 1 and 8	4	3	Confirmation	Fatigue, Gr 2	2
			Escalation	Embolism, Gr 4	1
			Escalation	Fatigue, Gr 3	
			Escalation	Myocardial infarction, Gr 3	1
			Escalation	Fatigue, Gr 3	1,6

Abbreviations: DET, DLT-equivalent toxicity; DLT, dose-limiting toxicity; Gr, grade; Q12H, every 12 hours.

^aEach cohort listing represents a different patient. Some patients exhibited >1 DLT/DET or the same DLT/DET in >1 cycle.

^bA DLT was defined as one of a list of specific adverse events occurring during cycle 1 of the dose-escalation phase that was possibly related to abemaciclib or the combination therapy. A DET was defined as an adverse event that would have met the criteria for DLT if it had occurred during cycle 1 for a patient enrolled in the dose-escalation phase, but that occurred in a later cycle or during any cycle for a patient in the dose-expansion phase.

(54%), thrombocytopenia (46%) anemia (42%), and leukopenia (21%). All-cause grade 3–4 TEAEs in ≥10% of patients were neutropenia (33%), anemia (25%), dyspnea (21%), and leukopenia (13%). High-grade diarrhea was greater in part B than part A (17% and 4%, respectively). Supplementary Table S3 explains dose reduction information for part B.

Part C. Among patients receiving the combination of abemaciclib and ramucirumab, across dose schedules, the most common nonhematologic TEAEs (any grade) were diarrhea (72%), fatigue (62%), nausea (49%), decreased appetite (41%), vomiting (31%), dyspnea (23%), and stomatitis (21%; Table 3). The most common hematologic TEAEs (any grade) were neutropenia (23%), thrombocytopenia (21%), anemia (13%), and leukopenia (8%). All-cause grade 3 to 4 TEAEs in ≥10% of patients were fatigue (23%), diarrhea (10%), neutropenia (10%), and thrombocytopenia (10%). High-grade diarrhea was exclusively associated with the 200-mg abemaciclib dose level combined with ramucirumab 10 mg/kg (day 1 regimen). Supplementary Table S3 explains dose reduction information for part C.

Pharmacokinetics

Figure 1 shows the mean plasma concentration–time profiles of abemaciclib and metabolites when administered in combination

with other therapies, after a single abemaciclib dose, and at steady state after multiple twice-daily abemaciclib doses. Following 150-mg repeated doses (Table 4), the steady-state, geometric mean abemaciclib C_{max} was 164 to 492 ng/mL and $AUC_{(0-t_{last})}$ was 1,300 to 3,460 (hr*ng/mL). Following the 200-mg repeated doses, the geometric mean abemaciclib C_{max} was 227 to 483 ng/mL and $AUC_{(0-t_{last})}$ was 1,380 to 3,460 (hr*ng/mL). Considering the high variability of the abemaciclib and metabolite pharmacokinetic parameters among the patient plasma samples, the exposure parameters for abemaciclib appeared similar among different combination therapies.

Pharmacokinetic parameters for pemetrexed and mean plasma concentration–time profiles are presented in Supplementary Table S4 and Supplementary Fig. S1, respectively (online appendix). Pharmacokinetic parameters for gemcitabine metabolite and mean plasma concentration–time profiles are presented in Supplementary Table S5 and Supplementary Fig. S2, respectively (online appendix). Considering the long half-life of ramucirumab and the limited sampling schedule (up to 10 hours postdose), no pharmacokinetics parameters were estimated for ramucirumab. Supplementary Fig. S3 presents mean serum concentration–time profiles of ramucirumab. Taken together, the results of this study indicate that there is no effect of abemaciclib on the pharmacokinetics of combination agents and that combination agents have no effect on the pharmacokinetics of the abemaciclib.

Table 3. TEAEs regardless of causality, by grade and doses

Adverse event ^a (N = 73)	Part A: Abemaciclib + Pemetrexed (n = 23)		Part B: Abemaciclib + Gemcitabine (n = 24)		Part C: Abemaciclib + Ramucirumab (n = 39)	
	Grade 3/4, n (%)	All grades, n (%)	Grade 3/4, n (%)	All grades, n (%)	Grade 3/4, n (%)	All grades, n (%)
	Abemaciclib dose		Abemaciclib dose		Abemaciclib dose	
Adverse event, grades 3/4 ^a	150 mg (n = 8), n (%)	200 mg (n = 15), n (%)	150 mg (n = 3), n (%)	200 mg (n = 21), n (%)	150 mg ^b (n = 20), n (%)	200 mg ^b (n = 19), n (%)
Diarrhea	1 (4)	18 (78)	4 (17)	14 (58)	4 (10)	28 (72)
Fatigue	4 (17)	18 (78)	6 (25)	18 (75)	9 (23)	24 (62)
Nausea	1 (4)	11 (48)	2 (8)	16 (67)	2 (5)	21 (54)
Neutropenia	15 (65)	15 (65)	8 (33)	13 (54)	4 (10)	9 (23)
Anemia	7 (30)	18 (78)	6 (25)	10 (42)	1 (3)	5 (13)
Decreased appetite	2 (9)	13 (57)	1 (4)	9 (38)	2 (5)	16 (41)
Thrombocytopenia	4 (17)	10 (44)	2 (8)	11 (46)	4 (10)	8 (21)
Vomiting	0	5 (22)	0	8 (33)	0	16 (41)
Blood creatinine increased	1 (4)	9 (39)	0	5 (21)	1 (3)	8 (21)
Dyspnea	5 (22)	9 (39)	5 (21)	5 (21)	1 (3)	9 (23)
Leukopenia	5 (22)	7 (30)	3 (13)	5 (21)	2 (5)	3 (8)
Stomatitis	1 (4)	8 (35)	0	2 (8)	3 (8)	8 (21)

Adverse event, grades 3/4 ^a	Abemaciclib dose		Abemaciclib dose		Abemaciclib dose	
	150 mg (n = 8), n (%)	200 mg (n = 15), n (%)	150 mg (n = 3), n (%)	200 mg (n = 21), n (%)	150 mg ^b (n = 20), n (%)	200 mg ^b (n = 19), n (%)
Diarrhea	0	1 (7)	0	4 (19)	0	4 (21)
Fatigue	3 (38)	1 (7)	1 (33)	5 (24)	5 (25)	4 (21)
Nausea	1 (13)	0	1 (33)	1 (5)	0	2 (11)
Neutropenia	6 (75)	9 (60)	2 (67)	6 (29)	1 (5)	3 (16)
Anemia	2 (25)	4 (27)	0	6 (29)	0	1 (5)
Decreased appetite	1 (13)	1 (7)	0	1 (5)	1 (5)	1 (5)
Thrombocytopenia	2 (25)	2 (13)	0	2 (10)	1 (5)	3 (16)
Vomiting	0	0	0	0	0	0
Blood creatinine increased	1 (13)	0	0	0	0	1 (5)
Dyspnea	1 (13)	4 (27)	1 (33)	4 (19)	1 (5)	0
Leukopenia	2 (25)	3 (20)	0	3 (15)	0	2 (11)
Stomatitis	1 (13)	0	0	0	2 (10)	1 (5)

^aTEAEs that occurred in ≥30% (all grades) in ≥1 part of the study are listed. No grade 5 events occurred for the TEAEs listed.
^bAmong part C patients who received 150 mg abemaciclib, 4 patients received 10 mg/kg ramucirumab on day 1, 12 patients received 8 mg/kg ramucirumab on days 1 and 8, and 4 patients received 10 mg/kg ramucirumab on days 1 and 8. Patients who received 200 mg abemaciclib received 10 mg/kg ramucirumab on days 1 and 8.

Response

The addition of abemaciclib to pemetrexed, gemcitabine, or ramucirumab resulted in a response rate of 4%–9% (all partial responses; Table 5). However, the combination of abemaciclib with pemetrexed and ramucirumab resulted in a DCR of 57% and 54%, respectively. In contrast, the DCR for the gemcitabine group was 25%. Median PFS results mirrored this trend. PFS for patients treated with abemaciclib plus pemetrexed was 5.55 months (95% CI: 1.81–10.05) and for

patients treated with abemaciclib plus ramucirumab was 4.83 months (95% CI: 2.60–6.93), with five patients still receiving study treatment with abemaciclib plus ramucirumab at the time of analysis. In contrast, PFS for patients treated with abemaciclib plus gemcitabine was 1.58 months (95% CI: 1.15–4.24).

Examination of treatment duration as a function of KRAS status (mutant versus wild type) did not reveal any relationship between patients receiving longer or shorter treatment and KRAS mutation

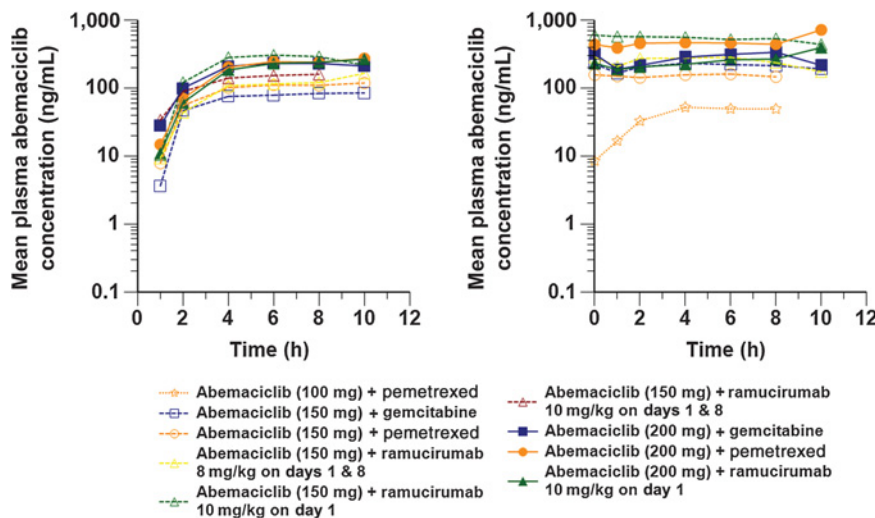


Figure 1. Abemaciclib plasma concentration over time. Mean plasma concentrations of abemaciclib are shown over time following single dose (left) and multiple dose (right) administration of abemaciclib (100, 150, or 200 mg) every 12 hours in combination with other agents as treatment for patients with stage IV NSCLC.

Table 4. Summary of abemaciclib exposure following oral administration every 12 hours in combination with therapies in patients with stage IV NSCLC

Combination therapy	Abemaciclib ^b	Geometric mean (CV%) ^a					
		Single dose			Multiple dose		
		C _{max} (ng/mL)	t _{max} ^c (hr)	AUC _(0–last) (hr·ng/mL)	C _{max} (ng/mL)	t _{max} ^c (hr)	AUC _(0–last) (hr·ng/mL)
Pemetrexed	200 mg BID (n = 15)	212 (80)	7.67 (4.00–10.00)	1050 (95)	483 ^d (41)	4.00 ^d (0.00–9.67)	3460 ^d (49)
	150 mg BID (n = 8)	114 (67)	6.09 (3.82–9.73)	654 (66)	146.40, 183.23 ^e	7.88, 0.00 ^e	1060, 1600 ^e
	100 mg BID (n = 2)				81.17, 46.43 ^e	4.00, 8.00 ^e	435, 190 ^e
Gemcitabine	200 mg BID (n = 19)	206 (73)	7.85 (3.92–10.00)	1150 (77)	304 ^f (66)	6.85 ^f (0.00–7.88)	2100 ^f (58)
	150 mg BID (n = 3)	80.6 (15)	9.75 (8.00–10.67)	509 (28)	288 ^g (71)	5.53 ^g (4.00–8.00)	2060 ^g (66)
Ramucirumab 10 mg/kg day 1	200 mg BID (n = 19)	195 (86)	6.00 (2.08–8.00)	919 (112)	227 ^h (17)	5.01 ^h (0.00–8.00)	1380 ^h (144)
	150 mg BID (n = 4)	312 (11)	6.00 (4.33–8.17)	1830 (18)	492 ⁱ (117)	1.00 ⁱ (0.00–7.97)	3460 ⁱ (125)
Ramucirumab 10 mg/kg days 1, 8	150 mg BID (n = 4)	159 (73)	7.00 (2.00–10.00)	885 (67)	377.4 ^j	10.00 ^j	3420 ^j
	100 mg BID (n = 1)				86.14 ^j	6.00 ^j	534 ^j
Ramucirumab 8 mg/kg days 1, 8	150 mg BID (n = 12)	103 (97)	7.91 (4.00–8.00)	549 (108)	246 (86)	2.00 (0.00–8.00)	1730 (95)

Abbreviations: AUC_(0–last), area under the concentration time curve from time 0 to last observed concentration; C_{max}, maximum plasma concentration; CV, coefficient of variation; n, number of observations.

^aGeometric mean and geometric CV% are provided for n ≥ 3; otherwise, actual values are provided.

^bPatients were started on 150 or 200 mg; later, doses were reduced to 100 mg due to dose reductions.

^cMedian and range are provided for t_{max}.

^dn = 9.

^en = 2.

^fn = 6.

^gn = 4.

^hn = 8.

ⁱn = 5.

^jn = 1.

(Supplementary Fig. S4, online appendix). Likewise, there was no apparent relationship between change in tumor size and KRAS status (Supplementary Fig. S5, online appendix). However, this interpretation was hampered by the large number of patients (51 of 85, 60%) with unknown KRAS status.

Discussion

Treatment options for patients with metastatic NSCLC are limited considerably after progressing on or after first-line treat-

ment. Among the available treatments, historical median PFS is only 2.0–4.5 months for second-line and likely shorter for later lines of treatment (8, 26). This trial gathers initial data regarding possible new drug combinations for second-line (or additional lines) treatment for metastatic NSCLC. On the basis of preclinical and clinical data, we conducted a multicenter phase Ib clinical study to test the safety and tolerability of oral abemaciclib combination therapy in patients with metastatic NSCLC.

MTD was not reached for combinations of abemaciclib with gemcitabine or pemetrexed. Both combination treatments used a

Table 5. Summary of efficacy measures

	Part A: Abemaciclib + Pemetrexed (N = 23)	Part B: Abemaciclib + Gemcitabine (N = 24)	Part C: Abemaciclib + Ramucirumab (N = 39)
Best overall response, n (%) ^a			
Complete response (CR)	0	0	0
Partial response (PR)	1 (4)	1 (4)	2 (5)
Stable disease (SD)	12 (52)	5 (21)	19 (49)
Progressive disease (PD)	3 (13)	9 (38)	6 (15)
Unknown	7 (30)	9 (38)	12 (31)
Disease control rate (CR + PR + SD)	13 (57)	6 (25)	21 (54)
Progression-free survival			
Number of events, n (%)	11 (48)	15 (63)	19 (49)
Number of patients censored, n (%)	12 (52)	9 (38)	20 (51)
Median PFS, months (95% CI)	5.55 (1.81, 10.05)	1.58 (1.15, 4.24)	4.83 (2.60, 6.93)

Abbreviations: CI, confidence interval; n, number of observations.

^aResponse criteria RECIST1.1 was used to determine response. Radiologic tumor assessments were performed locally at baseline and every 6 weeks thereafter until evidence of disease progression. Confirmation of complete or partial response was required for determination of best overall response. Stable disease required at least one post-baseline measurement at a minimum interval of 6 weeks after the first dose.

maximum abemaciclib dose of 200 mg twice daily. The combination of abemaciclib and ramucirumab 10 mg/kg on day 1 of a 21-day cycle did not reach a MTD. However, the day 1, 8 regimen declared an MTD at abemaciclib 150 mg twice daily plus ramucirumab 8 mg/kg on days 1 and 8 of 21-day cycle.

Abemaciclib was well tolerated in patients across study parts. The safety findings are consistent with AEs expected when combining abemaciclib with single-agent chemotherapy or antiangiogenic therapy. Treatment-related toxicities were generally manageable with dose adjustments and supportive care as needed. No unexpected safety signals or significant differences in AEs or serious adverse events were observed across study parts. Across combination treatments, 17%–25% patients had all-cause high-grade (3/4) fatigue. High-grade diarrhea appeared dose dependent and was well managed with antidiarrheal treatments and/or dose adjustments. In part A, one patient discontinued from treatment due to diarrhea. Overall, the incidence of AEs that resulted in treatment discontinuation of one or both study drugs was approximately 16%. In addition, safety findings for parts A and B are consistent with AEs expected when combining myelosuppressive agents with abemaciclib, resulting in an increased myelosuppressive effect (65% and 33% grade 3–4 neutropenia, respectively). As expected, the ramucirumab and abemaciclib combination had lower hematologic toxicity with a 23% overall incidence of neutropenia and 10% incidence of grade 3–4 neutropenia, which is consistent with the safety profile of single-agent abemaciclib (20). Across study parts, grade 3–4 TEAEs were generally reversible upon dose omission and/or dose reduction. The overall safety and tolerability of abemaciclib combination therapy are important in this heavily pretreated metastatic NSCLC population.

In general, abemaciclib can be dosed on a continuous twice-daily schedule when combined with single-agent chemotherapy or antiangiogenic therapy. The range of abemaciclib exposures achieved when combined with pemetrexed, gemcitabine, or ramucirumab is consistent with that observed in single-agent studies. There is no evidence of an effect of abemaciclib on the pharmacokinetics of pemetrexed, gemcitabine, or ramucirumab. The abemaciclib steady-state exposures achieved in this current study have been associated with inhibition of Rb phosphorylation and G₁ cell-cycle arrest in xenograft models (19). Furthermore, when used as a single agent in patients with cancer, abemaciclib doses of 150 or 200 mg Q12H were associated with sustained biochemical inhibition (reduced phosphorylated Rb) and phenotypic G₁ arrest (as assessed by reduced topoisomerase II alpha) expression in skin keratinocytes and tumor biopsies (20).

Tumor response data for the combinations of pemetrexed and ramucirumab with abemaciclib demonstrated preliminary anti-tumor activity relative to the abemaciclib and gemcitabine combination. The DCR for abemaciclib plus pemetrexed was 57% ($n = 23$), abemaciclib plus gemcitabine was 25% ($n = 24$), and abemaciclib plus ramucirumab was 54% ($n = 39$). As expected, the median PFS data followed the same trend as the DCR, namely greater for the pemetrexed combination (5.55 months) and ramucirumab combination (4.83 months) across dosing schedules, and lesser for the gemcitabine combination (1.58 months). No relationship was identified between *KRAS* mutation status and treatment duration or tumor response for the abemaciclib combinations explored among the 40% of patients with *KRAS* status

by local testing. Earlier studies found that among abemaciclib-treated patients, the DCR was greater in the *KRAS*-mutant population compared with the *KRAS* wild-type population, due largely to an increase in stable disease (20). In addition, *KRAS*-mutant NSCLC xenografts were found to be more sensitive to abemaciclib than wild-type NSCLC xenografts (20), also supporting the concept that the *KRAS* mutation identifies a population of NSCLC tumors sensitive to abemaciclib. However, no definitive efficacy conclusions can be reached due to the nonrandomized design and small sample size.

In summary, this trial confirmed the safety and tolerability of abemaciclib combined with single-agent chemotherapy or antiangiogenic therapy in previously treated unselected patients with advanced/metastatic NSCLC.

Disclosure of Potential Conflicts of Interest

E.S. Kim reports personal fees from Eli Lilly during the conduct of the study and personal fees from Celgene, AstraZeneca, and Boehringer Ingelheim outside the submitted work. K. Kelly reports personal fees from Lilly Advisory Board outside the submitted work. L.G. Paz-Ares reports personal fees and service in a medical advisory capacity for Roche, Eli Lilly, MSD, BMS, Novartis, AstraZeneca, Boehringer Ingelheim, Pfizer, Amgen, and Clovis outside the submitted work. P. Garrido is on the Advisory Board for Eli Lilly, Roche, AstraZeneca, MSD, AbbVie, Boehringer, BMS, Pfizer, and Guardant and has received personal fees from Roche, MSD, Boehringer, and BMS and a grant from Guardant. M. Gutierrez reports personal fees from Eli Lilly outside the submitted work. M. Provencio reports investigational funds from Lilly. J.W. Goldman has received research grants and is on the Advisory Board for Eli Lilly and Company. E.L. Johnson, P.K. Turner, S.R.P. Kambhampati, R. Beckmann, A. Hossain, and W.J. John are employees of Eli Lilly and Company. No potential conflicts of interest were disclosed by the other authors.

Authors' Contributions

Conception and design: E.S. Kim, E.L. Johnston, R. Beckmann, W.J. John, J.W. Goldman

Development of methodology: E.S. Kim, D. Mahadevan, W.J. John, J.W. Goldman

Acquisition of data (provided animals, acquired and managed patients, provided facilities, etc.): E.S. Kim, K. Kelly, L.G. Paz-Ares, P. Garrido, S. Jalal, D. Mahadevan, M. Gutierrez, M. Provencio, E. Schaefer, M. Shaheen, J.W. Goldman

Analysis and interpretation of data (e.g., statistical analysis, biostatistics, computational analysis): E.S. Kim, K. Kelly, S. Jalal, D. Mahadevan, M. Gutierrez, M. Shaheen, P.K. Turner, S.R.P. Kambhampati, A. Hossain, W.J. John, J.W. Goldman

Writing, review, and/or revision of the manuscript: E.S. Kim, K. Kelly, L.G. Paz-Ares, P. Garrido, S. Jalal, D. Mahadevan, M. Gutierrez, M. Provencio, E. Schaefer, M. Shaheen, E.L. Johnston, P.K. Turner, S.R.P. Kambhampati, R. Beckmann, A. Hossain, W.J. John, J.W. Goldman

Administrative, technical, or material support (i.e., reporting or organizing data, constructing databases): E.S. Kim, D. Mahadevan, S.R.P. Kambhampati

Study supervision: E.S. Kim, D. Mahadevan, M. Gutierrez, E.L. Johnston, W.J. John

Other (discussion on the results, analysis, and data interpretation): L.G. Paz-Ares

Acknowledgments

The authors thank the patients, investigators, and institutions involved in this study. They also thank Mary Dugan Wood for writing assistance. This work was supported by Eli Lilly and Company.

The costs of publication of this article were defrayed in part by the payment of page charges. This article must therefore be hereby marked *advertisement* in accordance with 18 U.S.C. Section 1734 solely to indicate this fact.

Received February 27, 2018; revised June 18, 2018; accepted July 30, 2018; published first August 6, 2018.

References

1. Stewart BW, Wild CP. World Cancer Report 2014.: Lyon, France; 2014. p. 351, 360.
2. Ettinger DS, Wood DE, Aisner DL, Akerley W, Bauman J, Chirieac LR, et al. Non-small cell lung cancer, version 5.2017. *J Natl Compr Canc Netw* 2017;15:504–35.
3. Sandler A, Gray R, Perry MC, Brahmer J, Schiller JH, Dowlati A, et al. Paclitaxel-carboplatin alone or with bevacizumab for non-small-cell lung cancer. *N Engl J Med* 2006;355:2542–50.
4. Reck M, von Pawel J, Zatloukal PV, Ramlau R, Gorbounova V, Hirsh V, et al. Overall survival with cisplatin-gemcitabine and bevacizumab or placebo as first-line therapy for nonsquamous non-small-cell lung cancer: results from a randomised phase III trial (AVAiL). *Ann Oncol* 2010;21:1804–09.
5. Thatcher N, Hirsch FR, Luft AV, Szczesna A, Ciuleanu TE, Dediu M, et al. Necitumumab plus gemcitabine and cisplatin versus gemcitabine and cisplatin alone as first-line therapy in patients with stage IV squamous non-small-cell lung cancer (SQUIRE): an open-label, randomised, controlled phase 3 trial. *Lancet Oncol* 2015;16:763–74.
6. Langer C, Gadgeel SM, Borghaei H, Papadimitrakopoulou VA, Patnaik A, Powell S, et al. Randomized, phase 2 study of carboplatin and pemetrexed with or without pembrolizumab as first-line therapy for advanced NSCLC: KEYNOTE-021 cohort G. *Ann Oncol* 2016;27:LBA46_PR.
7. Fossella FV, DeVore R, Kerr RN, Crawford J, Natale RR, Dunphy F, et al. Randomized phase III trial of docetaxel versus vinorelbine or ifosfamide in patients with advanced non-small-cell lung cancer previously treated with platinum-containing chemotherapy regimens. *J Clin Oncol* 2000;18:2354–62.
8. Garon EB, Ciuleanu TE, Arrieta O, Prabhash K, Syrigos KN, Goksel T, et al. Ramucirumab plus docetaxel versus placebo plus docetaxel for second-line treatment of stage IV non-small-cell lung cancer after disease progression on platinum-based therapy (REVEL): a multicentre, double-blind, randomised phase 3 trial. *Lancet* 2014;384:665–73.
9. Reck M, Kaiser R, Mellemegaard A, Douillard JY, Orlov S, Krzakowski MJ, et al. Nintedanib (BIBF 1120) plus docetaxel in NSCLC patients progressing after first-line chemotherapy: LUME Lung 1, a randomized, double-blind phase III trial. *J Clin Oncol* 2013;31:LBA8011.
10. Ciuleanu T, Stelmakh L, Cicen S, Miliauskas S, Grigorescu AC, Hillenbach C, et al. Efficacy and safety of erlotinib versus chemotherapy in second-line treatment of patients with advanced, non-small-cell lung cancer with poor prognosis (TITAN): a randomised multicentre, open-label, phase 3 study. *Lancet Oncol* 2012;13:300–8.
11. Hanna N, Shepherd FA, Fossella FV, Pereira JR, De Marinis F, Von Pawel J, et al. Randomized phase III trial of pemetrexed versus docetaxel in patients with non-small-cell lung cancer previously treated with chemotherapy. *J Clin Oncol* 2004;22:1589–97.
12. Reck M, Rodríguez-Abreu D, Robinson AG, Hui R, Csőszi T, Fülöp A, et al. Pembrolizumab versus chemotherapy for PD-L1-positive non-small-cell lung cancer. *N Engl J Med* 2016;375:1823–33.
13. Borghaei H, Paz-Ares L, Horn L, Spigel DR, Steins M, Ready NE, et al. Nivolumab versus docetaxel in advanced nonsquamous non-small-cell lung cancer. *N Engl J Med* 2015;373:1627–39.
14. Rittmeyer A, Barlesi F, Waterkamp D, Park K, Ciardiello F, von Pawel J, et al. Atezolizumab versus docetaxel in patients with previously treated non-small-cell lung cancer (OAK): a phase 3, open-label, multicentre randomised controlled trial. *Lancet* 2016;389:255–65.
15. Malumbres M, Barbacid M. Milestones in cell division: to cycle or not to cycle: a critical decision in cancer. *Nat Rev Cancer* 2001;1:222–31.
16. Sherr CJ. Cancer cell cycles. *Science* 1996;274:1672–7.
17. Weinberg RA. The retinoblastoma protein and cell cycle control. *Cell* 1995;81:323–330.
18. Gelbert LM, Cai S, Lin X, Sanchez-Martinez C, Del PM, Lallena MJ, et al. Preclinical characterization of the CDK4/6 inhibitor LY2835219: in-vivo cell cycle-dependent/independent anti-tumor activities alone/in combination with gemcitabine. *Invest New Drugs* 2014;32:825–37.
19. Tate SC, Cai S, Ajamie RT, Burke T, Beckmann RP, Chan EM, et al. Semi-mechanistic pharmacokinetic/pharmacodynamic modeling of the anti-tumor activity of LY2835219, a new cyclin-dependent kinase 4/6 inhibitor, in mice bearing human tumor xenografts. *Clin Cancer Res* 2014;20:3763–74.
20. Patnaik A, Rosen LS, Tolaney SM, Tolcher AW, Goldman JW, Gandhi L, et al. Efficacy and safety of abemaciclib, an inhibitor of CDK4 and CDK6, for patients with breast cancer, non-small cell lung cancer, and other solid tumors. *Cancer Discov* 2016;6:740–53.
21. Kelly K, Goldman JW, Garrido P, Jalal S, Mahadevan D, Gutierrez M, et al. Abemaciclib in combination with single agent options in stage IV NSCLC, a phase 1b study. *J Thorac Oncol* 2015;10:S550.
22. Ajani JA, Udrea A, Sarosiek T, Shenker M, Morgan C, Pikiel J, et al. A dose-response study of ramucirumab treatment in patients with gastric cancer/gastroesophageal junction adenocarcinoma: primary results of 4 dosing regimens in the phase 2 trial I4T-MC-JVDB. *Ann Oncol* 2017;28:698P.
23. US Department of Health and Human Services. Common Terminology Criteria for Adverse Events (CTCAE) Version 4.0. Bethesda, MD: NIH/National Cancer Institute; 2009.
24. Eisenhauer EA, Therasse P, Bogaerts J, Schwartz LH, Sargent D, Ford R, et al. New response evaluation criteria in solid tumours: revised RECIST guideline (version 1.1). *Eur J Cancer* 2009;45:228–47.
25. Kaplan EL, Meier P. Nonparametric estimation from incomplete observations. *J Am Stat Assoc* 1958;53:457–81.
26. Weiss JM, Stinchcombe TE. Second-line therapy for advanced NSCLC. *Oncologist* 2013;18:947–53.