A comparison of immunohistochemical assays and FISH in detecting the ALK translocation in diagnostic histological and cytological lung tumor material.

Le Quesne, J., Maurya, M., Yancheva, S. G., O'Brien, M., Popat, S., Wotherspoon, A. C., ..., Nicholson, A. G. (2014). A comparison of immunohistochemical assays and FISH in detecting the ALK translocation in diagnostic histological and cytological lung tumor material. Journal of thoracic oncology : official publication of the International Association for the Study of Lung Cancer, 9(6), 769-774. DOI: 10.1097/JTO.0000000000000157

Published in:
Journal of thoracic oncology : official publication of the International Association for the Study of Lung Cancer

Document Version:
Publisher's PDF, also known as Version of record

Queen's University Belfast - Research Portal:
Link to publication record in Queen's University Belfast Research Portal

Copyright © 2014 by the International Association for the Study of Lung Cancer
This is an open access article published under a Creative Commons Attribution-NonCommercial-NoDerivs License (https://creativecommons.org/licenses/by-nc-nd/4.0/), which permits distribution and reproduction for non-commercial purposes, provided the author and source are cited.

General rights
Copyright for the publications made accessible via the Queen's University Belfast Research Portal is retained by the author(s) and / or other copyright owners and it is a condition of accessing these publications that users recognise and abide by the legal requirements associated with these rights.

Take down policy
The Research Portal is Queen's institutional repository that provides access to Queen's research output. Every effort has been made to ensure that content in the Research Portal does not infringe any person's rights, or applicable UK laws. If you discover content in the Research Portal that you believe breaches copyright or violates any law, please contact openaccess@qub.ac.uk.
A Comparison of Immunohistochemical Assays and FISH in Detecting the ALK Translocation in Diagnostic Histological and Cytological Lung Tumor Material

John Le Quesne, MA (Cantab), PhD, MBBS, FRCPATH,* Manisha Maurya, PhD,† Slaveya G. Yancheva, FRCPATH,* Mary O’Brien, MD,‡ Sanjay Popat, FRCP, PhD,‡ Andrew C. Wotherspoon, MBBS, FRCPATH,§ David Gonzalez de Castro, PhD, FRCPATH,† and Andrew G. Nicholson, MBBS, DM, FRCPATH*

Introduction: Detection of the ALK rearrangement in a solid tumor gives these patients the option of crizotinib as an oral form of anticancer treatment. The current test of choice is fluorescence in situ hybridization (FISH), but various cheaper and more convenient immunohistochemical (IHC) assays have been proposed as alternatives.

Methods: Fifteen FISH-positive cases from patients, seven with data on crizotinib therapy and clinical response, were evaluated for the presence of ALK protein using three different commercially available antibodies: D5F3, using the proprietary automated system (Ventana), ALK1 (Dako), and 5A4 (Abcam). A further 14 FISH-negative and three uncertain (<15% rearrangement detected) cases were also retrieved. Of the total 32 specimens, 17 were excisions and 15 were computed tomography-guided biopsies or cytological specimens. All three antibodies were applied to all cases. Antibodies were semiquantitatively scored on intensity, and the proportion of malignant cells stained was documented. Cutoffs were set by receiver operating curve analysis for positivity to optimize correct classification.

Results: All three IHC assays were 100% specific but sensitivity did vary: D5F3 86%, ALK 79%, 5A4 71%. Intensity was the most discriminating variable overall, with a combination of proportion and intensity not improving the test. No FISH-negative IHC-positive cases were seen. Two FISH-positive cases were negative with all three IHC assays. One of these had been treated with crizotinib and had failed to show clinical response. The other harbored a second driving mutation in the EGFR gene.

Conclusions: IHC with all three antibodies is especially highly specific (100%) although variability sensitive (71%-86%), specifically in cases with scanty material. D5F3 assay was most sensitive in these latter cases. Occasional cases are IHC-positive but FISH-negative, suggesting either inaccuracy of one assay or occasional tumors with ALK rearrangement that do not express high levels of ALK protein.

Key Words: Pulmonary adenocarcinoma, ALK, Immunohistochemistry, Fluorescence in situ hybridization, Crizotinib

(J Thorac Oncol. 2014;9:769–774)

Rearrangements of the anaplastic lymphoma kinase (ALK) gene drive the malignant phenotype in 3% to 7% of primary lung adenocarcinomas. The resulting fusion protein, most often a fusion with echinoderm microtubule-associated protein-like 4 (ELM4), has a constitutively active tyrosine kinase domain. The small molecule drug crizotinib is a specific inhibitor of this kinase, and cases with the rearrangement respond to crizotinib treatment. Therefore, accurate, rapid, and inexpensive identification of tumors growing under the influence of translocated ALK is needed.

Currently the only test approved by the FDA is fluorescence in situ hybridization (FISH) using “break-apart” probes (Vysis, Abbott Molecular, Abbott Park, IL). This test is regarded as the “gold standard” for detection of rearrangements and is recommended by CAP/International Association for the Study of Lung Cancer/AMP. However, FISH is technically demanding, expensive, and many diagnostic laboratories lack either the expertise or the facilities to perform the test. Even in ideal circumstances, the results are often difficult to interpret, requiring the scrutiny of large numbers of individual cells by a highly experienced diagnostician. Furthermore, there are rare circumstances (such as small intrachromosomal inversion) in which the FISH test is negative but the tumor nevertheless expresses EML4-ALK fusion protein.

A cheaper and potentially more widely applicable method is immunohistochemistry (IHC); indeed, overexpression of ALK protein has been used in the diagnosis of anaplastic large-cell lymphoma for many years. Although
early studies in lung cancer lacked sensitivity, more recent studies have shown greater specificity and sensitivity, and recent international guidelines (CAP/International Association for the Study of Lung Cancer/AMP) have recommended that, if clinically validated, IHC may be used as a screening test for FISH testing. However, there have been few comparative studies on the most appropriate antibody to use.

The aim of this study was therefore to compare three different immunohistochemical assays, two being routine methods using antibodies widely used in the diagnosis of lymphoma, with the third being a proprietary system, including signal amplification, that is currently being promoted as an alternative to FISH (Ventana). We also evaluated the relationships between ALK rearrangement as detected by FISH, IHC, and patient response to therapy.

MATERIALS AND METHODS

Clinical Samples
The diagnostic archives from the Royal Brompton and Harefield NHS Foundation Trust and Royal Marsden hospitals from 2007 onwards were reviewed to identify cases with a diagnosis of lung adenocarcinoma that tested positive for an ALK rearrangement (>15% positive cells), and a randomly selected complementary group of cases with a normal ALK locus for comparison. We had been testing all primary lung tumors regardless of stage as part of a feasibility study, which led to a large number of early stage cases being included. More recently, our current policy is only to test advanced cases of non-squamous non–small-cell carcinoma using IHC screening with confirmatory FISH as per recently published guidelines. The cases under study are summarized in Table 1.

### TABLE 1. Summary Data of All Cases Included in the Study

| Tumor Type     | Specimen | Sex | Age | Stage              | Smoking History? | ALK FISH | TKI | Clinical Response |
|----------------|----------|-----|-----|--------------------|------------------|----------|-----|------------------|
| aCa            | Excision | F   | 61  | pT1a(2)/T3N0pM1b   | Not known        | Pos      | Yes | Yes              |
| aCa            | Biopsy   | F   | 47  | T4                 | Non-smoker       | Pos      | Yes | Yes              |
| NSCLC fav aCa  | Cytology | M   | 35  | T4 (pN3)           | Not known        | Pos      | Yes | Yes              |
| aCa            | Cytology | F   | 50  | T4B                | Non-smoker       | Pos      | Yes | Yes              |
| aCa            | Cytology | F   | 50  | T2N0M1B            | Non-smoker       | Pos      | Yes | No               |
| aCa            | Biopsy   | F   | 38  | T4B                | Non-smoker       | Pos      | Yes | Mixed            |
| aCa            | Cytology | M   | 35  | T4B                | Non-smoker       | Pos      | Yes | Yes              |
| Carcinosarcoma | Cytology | M   | 77  | T4N2M0             | Ex-smoker        | Uncertain| No   |                  |
| aCa            | Biopsy   | F   | 78  | T4N0M0             | Ex-smoker        | Uncertain| No   |                  |
| SCC            | Biopsy   | M   | 64  | T4N3M1B            | Ex-smoker        | Uncertain| No   |                  |
| NSCLC fav aCa  | Cytology | F   | 73  | T1apN3            | Non-smoker       | Pos      | No  |                  |
| aCa            | Excision | F   | 66  | pT2bN2             | Not known        | Pos      | No  | No               |
| aCa            | Excision | M   | 63  | pT1aN0             | Smoker           | Pos      | No  | No               |
| aCa            | Excision | M   | 54  | Recurrence (unknown) | Smoker          | Pos      | No  |                  |
| aCa            | Excision | M   | 45  | M1b                | Not known        | Pos      | No  |                  |
| NSCLC fav aCa  | Cytology | F   | 41  | pN2                | Not known        | Pos      | No  |                  |
| aCa            | Excision | F   | 64  | pT1bN0             | Non-smoker       | Pos      | No  |                  |
| aCa            | Cytology | F   | 28  | TXN0M1A            | Non-smoker       | Pos      | No  |                  |
| SCLC           | Biopsy   | M   | 30  | T4B                | Ex-smoker        | Neg      |     |                  |
| aCa            | Excision | M   | 74  | pT1bN0             | Not known        | Neg      |     |                  |
| NSCLC fav aCa  | Biopsy   | F   | 66  | pT2apN0            | Not known        | Neg      |     |                  |
| aCa            | Excision | M   | 71  | pT1a N0            | Ex-smoker        | Neg      |     |                  |
| aCa            | Excision | M   | 79  | pT2a N0            | Not known        | Neg      |     |                  |
| aCa            | Excision | M   | 63  | pT2aN0             | Smoker           | Neg      |     |                  |
| aCa            | Biopsy   | M   | 61  | pT1a N0            | Not known        | Neg      |     |                  |
| aCa            | Excision | F   | 54  | pT1a NX            | Non-smoker       | Neg      |     |                  |
| aCa            | Excision | F   | 48  | pT1b N0            | Smoker           | Neg      |     |                  |
| aCa            | Excision | F   | 66  | pT2b N0            | Non-smoker       | Neg      |     |                  |
| aCa            | Excision | F   | 82  | pT2b N0            | Ex-smoker        | Neg      |     |                  |
| aCa            | Excision | M   | 78  | pT2a N2            | Not known        | Neg      |     |                  |
| aCa            | Excision | M   | 53  | pT2a N2            | Ex-smoker        | Neg      |     |                  |
| aCa            | Excision | M   | 68  | pT1a N0            | Smoker           | Neg      |     |                  |

*aCa, adenocarcinoma; SCC, sodium citrate; NSCLC, non–small-cell lung cancer; TKI, tyrosine kinase inhibitor treatment (crizotinib); NSCLC fav aCa, NSCLC favoring adenocarcinoma on immunohistochemistry; FISH, fluorescence in situ hybridization.*
Paraffin blocks from a total of 32 diagnostic cases were retrieved; 15 of these had tested positive for the ALK rearrangement by FISH, three were uncertain (with <15% of cells showing rearrangement), and the remaining 14 cases were negative. All but two blocks dated from 2011 or later. Seventeen cases were blocks from tumor excisions (six of these were FISH positive) and the remainder were cytological or core biopsy/endobronchial ultrasound samples.

Data on treatment with crizotinib and response were retrieved from patient records. Cases with at least partial response to treatment defined according to the Response Evaluation Criteria in Solid Tumors criteria12 (i.e., at least 30% decrease in the sum of the longest diameters of target lesions) were designated as “responsive”.

The study was evaluated and classified as a service evaluation by the Imperial College Heads of Consortia and as such was exempt from Research Ethics Committee review.

Fluorescent In Situ Hybridization

Unstained 2 μm FFPE sections were put through deparaffinization and protease pretreatment steps before being denatured and hybridized overnight with the commercially available Vysis ALK dual color break apart probe (Abbott Molecular). Tissue sections then underwent SSC washes and were mounted in 4',6-diamidino-2-phenylindole for nuclei counterstaining. Results were analyzed and interpreted in accordance with probe manufacturer’s instructions.

Non-rearranged ALK showed as fused (yellow) signals. Rearranged ALK appeared as split 3' (red) and 5' (green) signals or an isolated 3' (red) signal. The recommended cutoff of 15% was used to interpret samples as positive or negative for ALK rearrangements in 200 nuclei.

Immunohistochemistry

An additional five sections were cut per case. Three were used for the immunohistochemical assays and the remaining two for negative controls.

Immunohistochemical assays were optimized using the monoclonal antibodies D5F3 (Ventana), ALK1 (Dako) and 5A4 (Abcam). The D5F3 assay was performed using the Ventana autostainer and a tyramide amplification step, as specified in the manufacturer’s protocol. The other assays were performed using a Dako autostainer with conventional polymer-based diaminobenzidine staining (no tyramide amplification). Details of the antibodies and conditions employed are given in Table 2.

Table 2. Immunohistochemical Assay Conditions Used

| Antibody | Supplier | Species | Antigen Retrieval | Dilution | Primary Incubation | Tyramide Amplification? |
|----------|----------|---------|-------------------|----------|--------------------|------------------------|
| D5F3     | Ventana  | Rabbit  | 92 minutes, 100°C, Cell conditioning 1 | 1:1      | 16 minutes, 37°C   | Yes                    |
| ALK1     | Dako     | Mouse   | 60 minutes, 97°C, high pH TRS         | 1:20     | 30 minutes, ambient temp | No                     |
| 5A4      | Abcam/Novocastra | Mouse | 60 minutes, 97°C, low pH TRS       | 1:50     | 30 minutes, ambient temp | No                     |

The D5F3 assay was performed using the proprietary Ventana immunostaining system. ALK1 and 5A4 assays were performed using a Dako autostainer.

Scoring

Immunohistochemically stained sections were examined without knowledge of FISH status by two pathologists independently. Scores for proportion and intensity of immunohistochemical staining were assigned by consensus.

The predominant intensity of staining was recorded on a scale of 0–3 (0 = negative, 1 = weak, 2 = moderate, 3 = strong). As the Ventana stain was more intense, due at least partly to the signal amplification step, the visual cutoffs for intensity scoring with this antibody were different (e.g., a “moderate” degree of intensity seen with the Ventana stain would usually be interpreted as “strong” on a section stained with 5A4). The proportion of malignant cells staining positive was recorded as per “Alfred” estrogen receptor scoring in breast cancer, on a scale of 0–5 (0 = 0%, 1 ≤ 1%, 2 = 1–10%, 3 = 11–33%, 4 = 34–66% and 5 ≥ 66%). A composite score (intensity + proportion) was also derived.

Statistical Analysis

Statistical analyses were performed using the STATA/IC package.

RESULTS

Fluorescence In Situ Hybridization

Slides were scored according to the manufacturer’s recommendations. Representative FISH images are shown in Figure 1A. The 15 positive cases all showed greater than 15% cells with rearranged ALK genes. Three cases were classified as “indeterminate”; these were all scanty biopsy or cytological samples with 10% to 15% of positively rearranged FISH signals. Seventeen further cases were FISH negative.

Immunohistochemistry

No signal was observed in negative controls. The intensity of staining between the three antibodies varied (Fig. 1B). IHC was impossible to assess in three cases with very scanty material (two FISH negative and one FISH positive). The Ventana assay using the D5F3 antibody gave the most intense cytoplasmic signal, but this was accompanied by higher background staining, which was especially noticeable in macrophages. The ALK1 and 5A4 antibody assays produced weaker staining but with less background. Of the two, 5A4 had marginally more background staining, especially in macrophages.

The value of both intensity and proportion scores was assessed. Cutoffs for positivity were set using ROC analysis to optimize correct classification of ALK status, using FISH
results as the standard (Table 3). The intensity score alone was seen to outperform both proportion and the aggregate score. Therefore intensity scoring using the optimized cutoff was used in subsequent analyses.

Concordance between FISH and IHC is shown in Table 4. No cases with negative FISH results and positive IHC were identified (100% specificity of IHC in these data). Sensitivity was the same (83%) for all three assays in excision specimens. In small biopsies and cytological specimens, however, the D5F3 antibody was the most sensitive. The ALK1 and 5A4 assays failed to identify a further one or two FISH-positive cases, respectively. All three assays failed to stain the same two cases which contain rearranged ALK genes detectable by FISH.

**Response to Therapy**

Seven cases with ALK rearrangements detected by FISH went on to receive crizotinib therapy. All but one showed at least a partial response. This crizotinib-refractory case showed no detectable ALK expression by all three IHC assays.

---

**TABLE 3.** Optimised Cutoff Values for Immunohistochemical Tests

|        | Intensity | Proportion | Combined |
|--------|-----------|------------|----------|
|        | Cutoff    | % Correctly Classified | Cutoff | % Correctly Classified | Cutoff | % Correctly Classified |
| DF3    | Ventana >1 | 93          | >4      | 80                      | >5     | 86                     |
| ALK1   | Dako >1   | 90          | >2      | 90                      | >3     | 90                     |
| 5A4    | Abcam >0  | 86          | >0      | 86                      | >0     | 86                     |

**TABLE 4.** Concordance of Immunohistochemistry (IHC) and Fluorescence In Situ Hybridization (FISH) Assays

| IHC   | FISH   | Neg/Indeterminate | Pos | Specificity (%) | Sensitivity (%) |
|-------|--------|-------------------|-----|-----------------|----------------|
| DF3   | Ventana Neg | 15  | 2   | 100 | 86  | 83  | 88  |
|       | Pos    | 0    | 12  |     |     |     |     |
| ALK1  | Dako Neg | 15  | 3   | 100 | 79  | 83  | 75  |
|       | Pos    | 0    | 11  |     |     |     |     |
| 5A4   | Abcam Neg | 15  | 4   | 100 | 71  | 83  | 63  |
|       | Pos    | 0    | 10  |     |     |     |     |
DISCUSSION

We have compared three different antibody assays for the ALK kinase domain to the current standard FISH assay in a set of archival tumors, including 15 FISH-positive cases. We found all three assays to be specific (100%) and sensitive (up to 86%), especially when a signal amplification technique is employed. Furthermore, data on response to crizotinib therapy in seven treated cases showed all but one case responded. The case that failed to respond to therapy was negative by all three IHC assays.

Of the three antibody methods compared, the D5F3 antibody using a Ventana proprietary assay performed the best, especially in scanty samples, which is likely to be a consequence of the tyramide signal amplification step incorporated into the Ventana assay. It is possible that the other two antibodies would perform as well, if a suitable signal amplification step were introduced. However, an assay using the 5A4 without tyramide amplification has been successfully applied by To et al in a recent comparable assessment of IHC as a test for ALK rearrangement. In a set of 373 tumors that included 20 ALK rearrangements as detected by FISH, their IHC assay was 99% specific and 100% sensitive. In contrast to this, we find 100% specificity and (at best) 86% sensitivity; that is to say, we identified rare FISH-positive IHC-negative cases, whereas To et al found occasional FISH-negative IHC-positive cases, which were proved to harbor EML4-ALK rearrangements by reverse transcription polymerase chain reaction (RT-PCR). It is unsurprising that we do not identify FISH-negative IHC-positive cases as we only examined 17 FISH-negative or indeterminate cases in comparison to the 356 examined by To et al. It is more notable that To et al do not identify FISH-positive, IHC-negative cases. This might be explained by their use of tissue microarrays for FISH, which is even more technically demanding and hard to interpret than FISH using whole sections.

This possible shortcoming of tissue microarray methods might be apparent in two other recent studies using tissue microarrays for a comparison of FISH with ALK1, 5A4 and D5F3 antibodies. Selinger et al describe 100% sensitivity for all three antibody assays. Conklin et al also find 100% sensitivity and a maximum specificity of 88% (again using the 5A4 antibody). Again, it may be that in both these additional studies the approach used hampered the identification of FISH-positive, IHC-negative cases because of the difficulty of applying FISH to TMA, especially when the primary test has been IHC and the FISH test is not “blind” to the IHC result.

Other recent studies compare various immunohistochemical assays and FISH for the detection of ALK rearrangements. As in this study, Sholl et al identify occasional FISH-positive, IHC-negative cases. They explain two cases by identifying co-existent mutations in other driving oncogenes (presumably thereby relieving the tumor “addiction” to ALK) and one by insufficient tumor material for accurate IHC assessment. Savic et al compared an immunocytochemical assay using the 5A4 antibody to FISH in cytological specimens and achieved a sensitivity of 93% and specificity of 96%, which is comparable with our findings in cytological and small biopsy cases (sensitivity 88%, specificity 100%).

In the current study, we detected two “false-negative” cases, which were positive by FISH and negative by all three IHC assays. This combination has two possible explanations. Firstly, they might represent tumors which are not expressing ALK protein at detectable levels, because of a false-positive FISH result, or an absence of addiction to rearranged ALK protein despite presence of recombined ALK DNA. These tumors are unlikely to respond to crizotinib. Secondly, they might represent a failure of the IHC assay, because of poor preservation of antigen, insufficient material or another technical error. In this case, crizotinib therapy would still be likely to be effective.

The study includes seven cases with positive FISH results with data on response to crizotinib. Six showed at least a partial response to crizotinib therapy, as assessed by Response Evaluation Criteria in Solid Tumors criteria. A single case showed no response, and this was one of the two “false negatives”. Thus, in this one case, the IHC test would have correctly predicted response. This was a scanty cytological specimen in which FISH interpretation was difficult, and only 20% of 515 cells showed rearranged ALK signals (fusion plus split red/green probes and fusion plus isolated red signal). Therefore, it seems possible that this represents a technical failure of the FISH assay.

The other case, an excision specimen, showed 39% of 626 cells with rearranged signals. It was also shown to harbor a driving mutation in a second gene; PCR testing demonstrated the loss of exon 19 of endothelial growth factor receptor. This has been described in another study that characterized two such “false-negative” cases. Thus, these tumors may well escape “oncogene addiction” to the ALK kinase activity, which would be consistent with indetectable ALK protein expression. Again, IHC would be expected to be the best predictor of response to tyrosine kinase inhibitor therapy in such cases.

It is essential to identify and molecularly characterize other “false-negative” cases that have received crizotinib therapy. In addition, it seems likely that IHC should guide treatments in “false-positive” cases that express high levels of ALK from genetic lesions that are invisible to the current FISH assay.

Although we identified no “false positives”, i.e., FISH-negative, IHC-positive cases, our sensitivity may be an overestimate (as judged by FISH) because of the small number of FISH-negative cases under study. Several studies have identified rare cases with rearrangements that are indetectable by FISH but detectable by IHC and confirmed by reverse-transcriptase PCR. Such cases would be expected to respond to crizotinib, and a recent study shows that at least one novel “FISH-indetectable” rearrangement does indeed drive the malignant phenotype.

One limitation of this study is the small number of cases under study, although 15 FISH-positive cases is comparable to most other studies. The relatively small number of FISH-negative cases may have affected our ability to identify FISH-negative, IHC-positive cases. However, the study design does permit an assessment of the sensitivity of the IHC assay, which is the most important consideration for a possible screening
test. Our comparison of the immunohistochemical assays was not directly equivalent, as the D5F3 assay included a proprietary tyramide signal amplification step, whereas the ALK1 and 5A4 assays were conducted using our routine diagnostic detection system. However, our study design also has several strengths. In particular, the use of archival diagnostic paraffin blocks, and FISH testing conducted in the course of routine diagnosis make the results of the study directly relevant to clinical practice.

In summary, we find IHC to be a highly sensitive (86%) and specific (100%) test for ALK rearrangement in lung adenocarcinoma. We find a slight advantage of a proprietary amplified assay (D5F3 Ventana) over two other antibodies with conventional DAB staining (ALK1 Dako and 5A4 Abcam), but only in scanty samples. Intensity of staining was the most discriminating measure, and the proportion of cells staining did not contribute. We identified two cases that were positive for the ALK rearrangement by FISH but negative by all immunohistochemical assays and suggest that in discordant cases the IHC test result may be more predictive of treatment response than FISH. Further discordant cases need to be examined to help guide the treatment of these cases.

Immunohistochemical testing is clearly at least a useful adjunct to FISH, and we feel that it is reasonable in routine practice to use a sensitive IHC assay as a screening test. The danger of missing treatable cases using this method (i.e., FISH-positive, IHC-negative, crizotinib-sensitive tumors) appears very small, especially when specimens contain adequate material. In difficult cases, further investigations such as re-biopsy and repeated IHC/FISH may be helpful.

REFERENCES

1. Inamura K, Takeuchi K, Togashi Y, et al. EML4-ALK lung cancers are characterized by rare other mutations, a TTF-1 cell lineage, an acinar histology, and young onset. Mod Pathol 2009;22:508–515.

2. Koivunen JP, Mermel C, Zejnullahu K, et al. EML4-ALK fusion gene and efficacy of an ALK kinase inhibitor in lung cancer. Clin Cancer Res 2008;14:4275–4283.

3. Shinmura K, Kageyama S, Tao H, et al. EML4-ALK fusion transcripts, but no NPM-, TPM3-, CLTC-, ATIC-, or TFG-ALK fusion transcripts, in non-small cell lung carcinomas. Lung Cancer 2008;61:163–169.

4. Soda M, Choi YL, Enomoto M, et al. Identification of the transforming EML4-ALK fusion gene in non-small-cell lung cancer. Nature 2007;448:561–566.

5. To KF, Tong JH, Yeung KS, et al. Detection of ALK rearrangement by immunohistochemistry in lung adenocarcinoma and the identification of a novel EML4-ALK variant. J Thorac Oncol 2013;8:883–891.

6. McDermott U, Iafraite AJ, Gray NS, et al. Genomic alterations of anaplastic lymphoma kinase may sensitize tumors to anaplastic lymphoma kinase inhibitors. Cancer Res 2008;68:3389–3395.

7. Kwak EL, Bang YJ, Camidge DR, et al. Anaplastic lymphoma kinase inhibition in non-small-cell lung cancer. N Engl J Med 2010;363:1693–1703.

8. Lindeman NI, Cagle PT, Beasly MB, et al. Molecular testing guideline for selection of lung cancer patients for EGFR and ALK tyrosine kinase inhibitors: guideline from the College of American Pathologists, International Association for the Study of Lung Cancer, and Association for Molecular Pathology. J Thorac Oncol 2013;8:823–859.

9. Murakami Y, Mitsudomi T, Yatabe Y. A Screening Method for the ALK Fusion Gene in NSCLC. Front Oncol 2012;2:24.

10. Rodig SJ, Mino-Kenudson M, Dacic S, et al. Unique clinicopathologic features characterize ALK-rearranged lung adenocarcinoma in the western population. Clin Cancer Res 2009;15:5216–5223.

11. Peled N, Palmer G, Hirsch FR, et al. Next-generation sequencing identifies and immunohistochemistry confirms a novel crizotinib-sensitive ALK rearrangement in a patient with metastatic non-small-cell lung cancer. J Thorac Oncol 2012;7:e14–e16.

12. Eisenhauer EA, Therasse P, Bogaerts J, et al. New response evaluation criteria in solid tumours: revised RECIST guideline (version 1.1). Eur J Cancer 2009;45:228–247.

13. Selinger CI, Rogers TM, Russell PA, et al. Testing for ALK rearrangement in lung adenocarcinoma: a multicenter comparison of immunohistochemistry and fluorescent in situ hybridization. Mod Pathol 2013;26:1545–1553.

14. Conklin CM, Kradock KJ, Have C, Laskin J, Couture C, Ionescu DN. Immunohistochemistry is a reliable screening tool for identification of ALK rearrangement in non-small-cell lung carcinoma and is antibody dependent. J Thorac Oncol 2013;8:45–51.

15. Sholl LM, Wermersmow Z, Gray SW, et al. Combined use of ALK immunohistochemistry and FISH for optimal detection of ALK-rearranged lung adenocarcinomas. J Thorac Oncol 2013;8:322–328.

16. Savic S, Bode B, Diebold J, et al. Detection of ALK-positive non-small-cell lung cancers on cytological specimens: high accuracy of immunocytochemistry with the 5A4 clone. J Thorac Oncol 2013;8:1004–1011.