Genomic Correlate of Exceptional Erlotinib Response in Head and Neck Squamous Cell Carcinoma

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IMPORTANCE Randomized clinical trials demonstrate no benefit for epidermal growth factor receptor (EGFR) tyrosine kinase inhibitors in unselected patients with head and neck squamous cell carcinoma (HNSCC). However, a patient with stage IVA HNSCC received 13 days of neoadjuvant erlotinib and experienced a near-complete histologic response.

OBJECTIVE To determine a mechanism of exceptional response to erlotinib therapy in HNSCC.

DESIGN, SETTING, AND PARTICIPANTS Single patient with locally advanced HNSCC who received erlotinib monotherapy in a window-of-opportunity clinical trial (patients scheduled to undergo primary cancer surgery are treated briefly with an investigational agent). Whole-exome sequencing of pretreatment tumor and germline patient samples was performed at a quaternary care academic medical center, and a candidate somatic variant was experimentally investigated for mediating erlotinib response.

INTERVENTION A brief course of erlotinib monotherapy followed by surgical resection.

MAIN OUTCOMES AND MEASURES Identification of pretreatment tumor somatic alterations that may contribute to the exceptional response to erlotinib. Hypotheses were formulated regarding enhanced erlotinib response in preclinical models harboring the patient tumor somatic variant MAPK1 E322K following the identification of tumor somatic variants.

RESULTS No EGFR alterations were observed in the pretreatment tumor DNA. Paradoxically, the tumor harbored an activating MAPK1 E322K mutation (allelic fraction 0.13), which predicts ERK activation and erlotinib resistance in EGFR-mutant lung cancer. The HNSCC cells with MAPK1 E322K exhibited enhanced EGFR phosphorylation and erlotinib sensitivity compared with wild-type MAPK1 cells.

CONCLUSIONS AND RELEVANCE Selective erlotinib use in HNSCC may be informed by precision oncology approaches.
The discovery of activating mutations in the epidermal growth factor receptor (EGFR) gene accelerated the clinical deployment of small-molecule tyrosine kinase inhibitors (TKIs) that effectively target the altered protein, yielding clinical benefit in many patients with EGFR-mutant lung adenocarcinoma. In unselected patients with head and neck squamous cell carcinoma (HNSCC), phase 1/2 trials suggested that EGFR TKIs might be clinically active. However, randomized phase 2 and 3 trials of EGFR TKIs for locally advanced or recurrent and/or metastatic HNSCC failed to show clinical benefit when added to standard-of-care regimens in unselected populations.

Complete responses to EGFR TKIs in solid tumors are extremely rare, poorly understood, and have been observed in EGFR wild-type settings. Genomic correlates of extraordinary response to targeted therapeutics have been demonstrated in other contexts, raising the possibility that a rare extreme response to erlotinib hydrochloride may result from somatic alterations in a patient’s tumor.

A man with locally advanced HNSCC received neoadjuvant erlotinib for 13 days in a window-of-opportunity clinical trial in which patients scheduled to undergo primary cancer surgery were treated briefly with an investigational agent. Unexpectedly, this patient experienced a near-complete histologic response without recurrence more than 2 years after therapy. Whole-exome sequencing of his pretreatment tumor and germline was performed to investigate molecular profiles permissive of this response.

Methods

Study Oversight
The patient provided written informed consent for an institutional review board–approved protocol to perform genomic profiling on tumor and germline DNA.

Pathologic Analysis and Sequencing
Tumor samples from pretreatment and surgical specimens were reviewed by an HNSCC pathologist (S.C.). Clinical human papillomavirus in situ hybridization testing detecting types 6, 11, 16, 18, 30, 31, 33, 35, 45, 51, and 52 was performed. DNA was extracted from tumor and matched germline, followed by whole-exome sequencing and analysis (eMethods in the Supplement).

Experimental Analysis
*MAPK1 E322K* (HSC-6), wild-type *MAPK1* (CAL-33), and *MAPK1*-deleted (FaDu) HNSCC cells were identified using published resources. *MAPK1*-deleted cells were transfected with vector, wild-type *MAPK1* or *MAPK1* E322K expression constructs. Western blotting was performed for EGFR and MAPK pathway members as described previously. Viability and senescence following erlotinib treatment were evaluated in engineered FaDu cells and in HSC-6 cells transfected with MAPK-targeting or control small interfering RNA (eMethods in the Supplement).

Results

Genetic Analysis of the Pretreatment Tumor
The mean target coverage across the exome was 85X in the tumor sample and 183X in the germline sample. There were 39 missense mutations, 3 nonsense mutations, and 2 frame shift deletions, for a nonsilent mutation rate of 2.00 mutations/Mb (eTables 1 and 2 in the Supplement). No somatic

At a Glance

- The presence of MAPK1 E322K predicts resistance to erlotinib therapy in preclinical models but was identified in the tumor of an extraordinary responder.
- Engineered MAPK1 E322K cells exhibit enhanced erlotinib sensitivity compared with MAPK1 wild-type cells.
- MAPK1 E322K induces EGFR activation in head and neck squamous cell carcinoma (HNSCC) in vitro models.
- MAPK1 E322K is present at low frequencies in HNSCC and cervical cancers.
mutations, short insertions or deletions, or copy number alterations were observed in EGFR (Figure 2A and eTables 3 and 4 in the Supplement), PTEN, PIK3CA, or HRAS. Heuristic analysis identified somatic alterations in 4 clinically or biologically relevant cancer genes (Figure 2B): TP53, ABL2, ARID1A, and MAPK1.

The MAPK1 alteration (allelic fraction, 0.13; median, 0.15) was particularly unexpected in this patient. MAPK1 codes for ERK2, a mitogen-activated signaling (MAPK) pathway member downstream of Raf and MEK (Figure 2C), and the E322 locus is highly conserved across species (Figure 2D). The E322K mutation occurs in approximately 1% of HNSCC and 8% of cervical squamous cell carcinomas.

MAPK1 E322K causes constitutive activation of ERK2. MAPK1 amplification, which may also activate ERK signaling, confers EGFR TKI resistance in lung adenocarcinoma preclinical models. Thus, the presence of MAPK1 E322K would be predicted to result in ERK signaling activation and intrinsic resistance, rather than exquisite sensitivity, to EGFR-directed therapies.

**MAPK1 E322K Effects on EGFR Activation and Erlotinib Sensitivity**

To explore the possibility that the MAPK1 E322K mutation may have paradoxically conferred exquisite dependency on aberrant EGFR signaling in this patient, wild-type MAPK1 (CAL-33) and MAPK1 E322K (HSC-6) HNSCC cells were analyzed for relative EGFR protein and pathway activation (Figure 3A). The HNSCC cells harboring endogenous MAPK1 E322K expressed higher basal levels of PY1068 EGFR, a surrogate for activated EGFR, and downstream AKT signaling compared with cells expressing wild-type MAPK1 or vector control cells. Finally, knockdown of ERK2 protein levels in MAPK1 E322K cells expressed higher basal levels of PY1068 EGFR (Figure 3B) and demonstrated significantly increased senescence (Figure 3C and eFigure 1 in the Supplement) and significantly increased cell death (eFigure 2 in the Supplement) following erlotinib treatment compared with cells expressing wild-type MAPK1 or vector control cells. Finally, knockdown of ERK2 protein levels in MAPK1 E322K cells (HSC-6) resulted in reduced cell death following erlotinib treatment compared with parental and nontargeting small interfering RNA transfected cells (eFigure 3 in the Supplement). In aggregate, these data are consistent with the clinical observation that the presence of MAPK1 E322K can contribute to erlotinib sensitivity in HNSCC.

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**Figure 1. Clinical Course and Histologic Findings**

A. Time course for the patient’s clinical experience, highlighting the number of days receiving erlotinib and the time elapsed since surgery. D indicates day. B and C. Representative histologic analysis images of the pretreatment tumor biopsy confirm squamous cell carcinoma (hematoxylin-eosin; B, original magnification ×40; C, original magnification ×100). D and E, representative histology images from surgical specimens taken after 13 days of erlotinib therapy (hematoxylin-eosin; D, original magnification ×40; E, original magnification ×100).
Discussion

We identified a patient with stage IVA HNSCC who experienced an exceptional response to a 13-day course of neoadjuvant erlotinib. This response occurred in the context of an activating somatic MAPK1 E322K mutation and thus was particularly noteworthy given that MAPK1 amplification or activation predicts erlotinib resistance (rather than sensitivity) in preclinical cancer models. We then demonstrated that EGFR and downstream pathway members show increased activation in HNSCC cells harboring MAPK1 E322K compared with wild-type MAPK1 cells. We speculate that EGFR dependency may have resulted from an activated Erk-mediated increase in EGFR ligand production in this patient’s tumor. Increased levels of amphiregulin as a result of Erk activation have been reported for bronchial epithelial cells, and high levels of amphiregulin have been associated with response to EGFR TKIs.

Although only observed in a single patient, this finding may have important clinical implications. This type of genomic event would not occur at sufficient frequency to influence the results of erlotinib-oriented phase 2/3 studies in unselected patients with HNSCC. Instead, this case highlights the potential contribution of the “long tail” of clinically relevant cancer genes that may prove actionable in some patients.

This study also demonstrates how different activating alterations in the same gene may lead to clinically distinct responses to the same therapy; the effect of 2 different ERK-activating mechanisms (point mutation or amplification) may not be clinically equivalent. This result indicates the promise of more expansive precision oncology efforts linking genomics with clinically annotated cases, so that phenotype-to-genotype relationships can be rapidly identified and studied. Toward this end, it is unknown whether this MAPK1 E322K mutation may contribute to similar sensitivity to erlotinib therapy in other tumor types (eg, cervical cancer), or with antibody-mediated EGFR inhibition (eg, cetuximab). This will need to be assessed in additional studies.

There are limitations to this study. First, whereas the degree of response to brief erlotinib therapy was impressive, the relative contributions of erlotinib or surgery for the duration of response cannot be definitively determined. Furthermore, whereas forced overexpression of MAPK1 E322K did...
Increase erlotinib sensitivity in MAPK1-deleted HNSCC cells, the MAPK1 E322K mutation's effect on erlotinib sensitivity was modest. The preclinical models examined here were not derived from this patient’s tumor; thus, they may have arisen through different carcinogenic paths or harbor additional alterations that confound the study of erlotinib sensitivity. Conversely, the patient’s exceptional response may have been enhanced by other somatic alterations. Importantly, although experimental studies did not fully phenocopy the exquisite erlotinib sensitivity of the patient tumor, the results tracked with the patient’s response and countered the expectation that MAPK1 E332K would confer erlotinib resistance.

Conclusions

Broadly, these results support the notion that outlier genomics (eg, the National Cancer Institute’s Exceptional Responders Initiative) may yield unexpected insights into cancer biology and clinical management for both approved and investigational therapies.
Mechanism of Exceptional Erlotinib Response

Brief Report Research

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REFERENCES


