Combined Inhibition of c-Src and Epidermal Growth Factor Receptor Abrogates Growth and Invasion of Head and Neck Squamous Cell Carcinoma

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Abstract

Purpose: Increased expression and/or activation of epidermal growth factor receptor (EGFR) is associated with tumor progression and poor prognosis in many cancers, including head and neck squamous cell carcinoma (HNSCC). Src family kinases, including c-Src, mediate a variety of intracellular or extracellular signals that contribute to tumor formation and progression. This study was undertaken to elucidate the role of c-Src in the growth and invasion of HNSCC and to determine the effects of combined targeting of EGFR and Src kinases in HNSCC cell lines.

Experimental Design: HNSCC cells were engineered to stably express a dominant-active form of c-Src and investigated in cell growth and invasion assays. The biochemical effects of combined treatment with the Src inhibitor AZD0530, a potent, orally active Src inhibitor with Bcr/Abl activity, and the EGFR kinase inhibitor gefitinib were examined, as well as the consequences of dual Src/EGFR targeting on the growth and invasion of a panel of HNSCC cell lines.

Results: HNSCC cells expressing dominant-active c-Src showed increased growth and invasion compared with vector-transfected controls. Combined treatment with AZD0530 and gefitinib resulted in greater inhibition of HNSCC cell growth and invasion compared with either agent alone.

Conclusions: These results suggest that increased expression and activation of c-Src promotes HNSCC progression where combined targeting of EGFR and c-Src may be an efficacious treatment approach.

Head and neck squamous cell carcinoma (HNSCC) is characterized by a marked propensity for local invasion and cervical lymph node metastasis that is associated with adverse outcomes. Despite advances in the treatment of HNSCC, up to 50% of patients with this disease develop locoregional recurrence, distant metastasis, and/or a second primary cancer. For patients who experience treatment failure after first-line therapy for recurrent or metastatic disease, retrospective analysis has shown a median overall survival of only 3 to 4 months even with treatment, underscoring the aggressiveness of this malignancy and the need for more effective therapies.

Signaling through the epidermal growth factor receptor (EGFR; HER1) has been implicated in various processes that contribute to cancer progression, including cell cycle regulation, inhibition of apoptosis, angiogenesis, tumor cell motility, invasion, and metastasis (2, 3). Overexpression of EGFR occurs in a variety of solid tumors, including the majority of HNSCC (4–6). We reported previously that high levels of EGFR in HNSCC tumors are correlated with increased regional lymph node metastasis and decreased survival (7). Advanced stage (8), increased tumor size (8), increased recurrence (9), and decreased radiation sensitivity (10) have also been correlated with high tumor EGFR levels. Overexpression of EGFR in HNSCC tumors and the correlation with poor clinical outcome implicate EGFR in the development and progression of HNSCC, and suggest a role for EGFR as a target for cancer therapy. EGFR targeting using a monoclonal antibody approach in combination with radiation has shown efficacy and served as the basis for Food and Drug Administration approval of cetuximab for HNSCC (11).

However, despite promising results in preclinical models, clinical trials using EGFR tyrosine kinase inhibitors as monotherapy in patients with advanced or metastatic HNSCC have shown relatively low therapeutic responses (4-10%; refs. 12, 13). The c-Src protein is a 60-kDa nonreceptor tyrosine kinase that is emerging as a potential target for cancer therapy. c-Src regulates signals from multiple cell surface molecules, including integrins (14), growth factors (15), and G protein–coupled receptors (16, 17). Elevated c-Src protein levels and/or kinase activity has been reported in a variety of cancers, including HNSCC (18–20). The activation of c-Src has been reported to mediate several aspects of tumor growth and progression, including proliferation, migration, invasion, survival, and...
Combined Inhibition of c-Src and EGFR in HNSCC

Angiogenesis (21–26). We showed previously that c-Src is activated downstream of EGFR in HNSCC (20). The present study was designed to test the hypothesis that increased c-Src activation contributes to HNSCC progression and that blockade of both c-Src and EGFR would enhance antitumor effects compared with targeting either pathway alone.

AZD0530 is a small-molecule Src inhibitor that blocks the ATP-binding site of Src kinases and is also an inhibitor of kinases with closely related structures, such as Abl (27). Phase I testing of AZD0530 is complete, and phase II studies are under way in several solid tumors, including HNSCC (28). We elected to use AZD0530, which has not been studied previously in HNSCC, to determine if dual inhibition of EGFR and Src was a rationale treatment approach that could ultimately be tested in patients with HNSCC.

Materials and Methods

Cells and reagents. Cell lines derived from HNSCC patients were used for these studies. The 1483 HNSCC cell line was derived from a tumor in the oropharynx (29). Cal-33 cell line was derived from a patient with squamous cell carcinoma of the tongue (30). The U-M-22B cell line was derived from a metastatic cervical lymph node of a patient with a hypopharyngeal cancer (31), whereas the PCI-37B cell line was derived from a metastatic lymph node of a patient with laryngeal cancer (32). Cell lines were maintained in DMEM supplemented with heat-inactivated fetal bovine serum (FBS) at 37°C with 5% CO₂. The Src inhibitor AZD0530 and the EGF-specific tyrosine kinase inhibitor gefitinib (ZD1839) were obtained from AstraZeneca. Both reagents were dissolved in DMSO at 10 mmol/L, stored at -20°C, and diluted with DMEM before use.

Transfection of HNSCC cells with dominant-active c-Src. HNSCC cells (1483) were transfected with a pUSEamp vector (Upstate Biotechnology, Inc.) containing mutant Src (Y529F) cDNA using LipofectAMINE 2000 Transfection Reagent (Invitrogen) according to the manufacturer’s recommendations. Stably transfected clones were selected for resistance to the neomycin analogue (400 μg/mL G418; Invitrogen). Dominant-active (DA) c-Src was generated by mutation of Tyr229 to phenylalanine, which eliminated the inhibitory phosphoryrosine at position 529. HA-tagged DA c-Src HNSCC cells were also generated separately by transfection with a DA Src construct engineered to contain an HA tag. Vector-transfected control clones were established by stable transfection of the cells with pUSEamp control vector.

Biochemical dose response to AZD0530. HNSCC cells were cultured in 10% FBS-containing media. When cells were 70% to 80% confluent, they were treated with AZD0530 (1-10 μM) or DMSO for 2 h before lysis. Immunoblotting was done with pY418 Src antibody, anti-c-Src antibody, phosphorylated focal adhesion kinase (pFAK) Tyr416, and total FAK.

Matrigel invasion assay. The invasive ability of HNSCC cells was measured using Matrigel-coated modified Boyden inserts with a pore size of 8 μm (Becton Dickinson). Cells were plated in triplicate at a density of 1 x 10⁴ per well in serum-free DMEM with the control vehicle (DMSO), AZD0530 at (IC₅₀ value), gefitinib (at IC₅₀ value), or the combination of AZD0530 and gefitinib (both at IC₅₀ values) in DMEM with 10% FBS. At selected time points, cells were trypsinized and stained with trypan blue and vital cells were counted using a hemocytometer.

Western blotting. Cell lines were lysed in detergent containing 1% NP40, 150 mmol/L NaCl, 1 mmol/L EDTA, 0.1 mmol/L phenyl-methylsulfonyl fluoride, 1 μg/mL leupeptin, and 1 μg/mL aprotinin, and protein levels were determined using the Bio-Rad protein assay method (Bio-Rad Laboratories). Forty micrograms of total protein was separated on 8% SDS-PAGE gels and transferred to nitrocellulose membranes using a semidry transfer machine (Bio-Rad Laboratories). Membranes were blocked with 5% skim milk/TBS with Tween 20 solution for 1 h at room temperature and incubated with primary antibodies in 5% skim milk in TBS-T overnight at 4°C. After washing with TBS-T thrice, membranes were incubated for 1 h with horseradish peroxidase–conjugated secondary antibody (Bio-Rad Laboratories) 1:3,000 diluted in 5% skim milk in TBS-T. The filters were rinsed with TBS-T thrice, and the blot was developed using Luminol Regent (Santa Cruz Biotechnology, Inc.) by autoradiography.

Antibodies used for blotting included an anti–phosphorylated Src polyclonal antibody (Tyr416; BioSource International); c-Src (Santa Cruz Biotechnology, Inc.); HA (Covance); β-actin (Ab-1) monoclonal mouse IgM (Oncogene Research Products, Boston); phosphorylated p44/42 mitogen-activated protein kinase (MAPK; Thr202/Tyr204), p44/42 MAPK, phosphorylated AKT (Ser473), AKT, phosphorylated signal transducers and activators of transcription 3 (STAT3; Tyr705), and STAT3 (all from Cell Signaling Technology); phosphorylated FAK (Tyr925; BioSource International); and FAK (Santa Cruz Biotechnology, Inc.).

Statistical analysis. For invasion and proliferation studies, the statistical significance of differences in the number of invading cells or viable cells was assessed by use of ANOVA or Wilcoxon-Mann-Whitney one-tailed exact test.

Results

Characterization of DA c-Src HNSCC clones. To determine the role of enhanced c-Src activation in HNSCC, DA c-Src HNSCC clones were established by stable transfection of a representative cell line (1483) with a DA c-Src construct. We also generated HA-tagged DA c-Src clones in 1483 using a similar strategy. The COOH terminus of c-Src contains the Tyr229 residue, which can bind to the SH2 domain when phosphorylated. Interactions between the COOH terminus and the SH2 domain and between the kinase domain and the SH3 domain cause the c-Src molecule to assume a closed configuration that obscures the kinase domain and reduces its potential for substrate interaction (33, 34). The kinase activating mutation in the DA c-Src construct that we used contains a substitution of phenylalanine for tyrosine at position 529 in the COOH terminus. This Y529F mutation renders the SH1 kinase domain open by hindering the binding between the COOH terminus and the SH2 domain of the c-Src molecule, which, in turn, enhances the potential for substrate interaction. After transfection, 1483 cells were cultured with 400 μg/mL G418 and G418-resistant clones were obtained. After cell lysis, protein extracts were fractionated on an 8% SDS-PAGE gel. Immunoblots were probed with pY418 c-Src antibody and c-Src antibody to evaluate levels of phosphorylated and total c-Src, respectively. Compared with the vector-transfected controls, DA c-Src–transfected clones showed a 2-fold to 3-fold increase in c-Src tyrosine phosphorylation at position 418, as well as increased total c-Src (Fig. 1A and B).

Expression and activation of c-Src in vector
control clones were not different from levels detected in nontransfected parental 1483 cells (data not shown).

Increased c-Src enhances HNSCC cell invasion and proliferation. Decreased activity of c-Src by dominant-negative (DN) c-Src transfection or treatment with a Src inhibitor has been reported to abrogate invasion of cancer cells, including HNSCC ([17, 20, 35, 36]). Breast cancer cells with higher EGFR and c-Src levels have been shown to have a more invasive phenotype ([37]). To determine whether increased c-Src could enhance invasion and/or proliferation in HNSCC cells, Matrigel invasion and growth assays were done. In addition to HNSCC cells stably expressing DA c-Src, we also evaluated clones from the same cell line stably transfected with a DN c-Src construct, as described previously ([20]). As shown in Fig. 2, DA c-Src–transfected cells were 2.6-fold more invasive than vector-transfected control cells under these conditions (P = 0.0143), whereas DN c-Src–transfected cells were 6-fold less invasive than vector-transfected control cells (P = 0.0143). A similar trend was seen in another set of experiments using 1483 vector–transfected control clone 1 (VC #1), with 1483 HA-DA c-Src clone #62 (data not shown).

To assess proliferation, cell counting experiments using trypan blue dye exclusion were done. In 1% FBS, the growth of DA c-Src–transfected cells (DA c-Src #6) and DN c-Src–transfected cells was 77.7% higher (P = 0.0043) and 44.6% lower (P = 0.0422), respectively, than vector-transfected control cells (VC #3; Fig. 3A). In another experiment, the rate of cell proliferation was increased in DA c-Src #62 compared with 1483 vector–transfected control cells (VC #1) and DN-transfected c-Src when grown in 1% FBS (Fig. 3B). Similar results were observed in another HNSCC cell line stably transfected with DA c-Src (Fig. 3C and D). These results suggest that HNSCC cell invasion and growth may be enhanced by increased expression and activation of c-Src.

AZD0530 inhibits Src family kinase activity in vitro. AZD0530 is a dual-specific Src/Abl kinase inhibitor that has been reported to decrease activated Src in tamoxifen-resistant breast cancer cells ([37]). To determine the effect of AZD0530 on c-Src expression and activation in HNSCC cells, the expression of total and phosphorylated c-Src and its downstream target FAK was evaluated. UM-22B, 1483, and PCI-37B were treated with 1 to 10^4 nmol/L AZD0530 or DMSO for 2 hours. After protein extraction, immunoblots were probed with the Src family kinase-specific pY418 antibody and an anti–c-Src antibody. AZD0530 inhibited the activity of Src family kinases in a dose-dependent manner and caused a substantial decrease of pY418 Src at 1 μmol/L in the cell lines examined (Fig. 4A). We also saw a concomitant decrease in expression levels of pFAK Tyr861 (an Src-dependent phosphorylation site) at this concentration of AZD0530 in these cells. Inhibition of c-Src activation by AZD0530 at a concentration of 1 μmol/L is consistent with previous findings in breast cancer cells ([37]). The Cal-33 HNSCC cell line was more sensitive to AZD0530 than the other three HNSCC cell lines, with an IC50 value of 0.6 μmol/L. AZD0530 at this concentration also decreased pY418 Src and pFAK Tyr861 levels. In addition, expression of E-cadherin was increased by AZD0530 in this cell line (Fig. 4B).

Combined inhibition of c-Src and EGFR abrogates invasion of HNSCC cells. Src family kinases interact with many receptor tyrosine kinases, including EGFR ([38]). EGFR has been reported to activate Src through a variety of mechanisms. We reported previously that Src family kinases also regulate gastrin-releasing peptide–induced EGFR proligand cleavage, leading to downstream EGFR and MAPK activation in HNSCC, which contributes to cell proliferation and invasion ([17]). Gefitinib is an orally active synthetic quinazoline derivative that binds EGFR and inhibits the activation of the receptor in a reversible manner. To test whether the combination of AZD0530 and gefitinib

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**Fig. 1.** Characterization of DA c-Src clones. A, HNSCC cells (1483) were transfected with a DA c-Src construct (Upstate Biotechnology) followed by isolation of stable clones in G418–containing media (400 μg/mL). Expression of Tyr418 phosphorylation and total c-Src were examined by immunoblotting with pY418 Src antibody (BioSource International) and anti–c-Src antibody (Santa Cruz Biotechnology, Inc.). Actin is shown as a control for loading (Oncogene Research). B, additional HA-tagged DA c-Src clones were generated in 1483 cells. A representative Western blot showing increased expression of pY418 Src, as well as total c-Src, is shown, in conjunction with expression of the HA-tag. The experiment was repeated thrice with similar results.

**Fig. 2.** Invasion of DA and DN c-Src HNSCC cells. Representative vector–transfected control, DN c-Src – transfected, and DA c-Src – transfected HNSCC (1483) clones (DA c-Src #6) were serum-starved for 4 d and then plated at a density of 5 × 10^5 cells per well in serum-free DMEM in Matrigel-coated inserts. Lower wells contained DMEM with 10% FBS. After 48 h at 37°C in a 5% CO2 incubator, the cells in the insert were removed by wiping gently with a cotton swab. Cells on the reverse side of the insert were fixed and stained with Hema 3 (Fisher Scientific) according to the manufacturer’s instructions. Invading cells in four to eight representative fields were counted using light microscopy at 200× magnification. The experiment was repeated four times with similar results.

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**Fig. 3.** Cell proliferation experiments. A, to assess proliferation, cell counting experiments using trypan blue dye exclusion were done. In 1% FBS, the growth of DA c-Src–transfected cells (DA c-Src #6) and DN c-Src–transfected cells was 77.7% higher (P = 0.0043) and 44.6% lower (P = 0.0422), respectively, than vector-transfected control cells (VC #3; Fig. 3A). In another experiment, the rate of cell proliferation was increased in DA c-Src #62 compared with 1483 vector–transfected control cells (VC #1) and DN-transfected c-Src when grown in 1% FBS (Fig. 3B). Similar results were observed in another HNSCC cell line stably transfected with DA c-Src (Fig. 3C and D). These results suggest that HNSCC cell invasion and growth may be enhanced by increased expression and activation of c-Src.

**Fig. 4.** AZD0530 inhibits Src family kinase activity in vitro. AZD0530 is a dual-specific Src/Abl kinase inhibitor that has been reported to decrease activated Src in tamoxifen-resistant breast cancer cells ([37]). To determine the effect of AZD0530 on c-Src expression and activation in HNSCC cells, the expression of total and phosphorylated c-Src and its downstream target FAK was evaluated. UM-22B, 1483, and PCI-37B were treated with 1 to 10^4 nmol/L AZD0530 or DMSO for 2 hours. After protein extraction, immunoblots were probed with the Src family kinase-specific pY418 antibody and an anti–c-Src antibody. AZD0530 inhibited the activity of Src family kinases in a dose-dependent manner and caused a substantial decrease of pY418 Src at 1 μmol/L in the cell lines examined (Fig. 4A). We also saw a concomitant decrease in expression levels of pFAK Tyr861 (an Src-dependent phosphorylation site) at this concentration of AZD0530 in these cells. Inhibition of c-Src activation by AZD0530 at a concentration of 1 μmol/L is consistent with previous findings in breast cancer cells ([37]). The Cal-33 HNSCC cell line was more sensitive to AZD0530 than the other three HNSCC cell lines, with an IC50 value of 0.6 μmol/L. AZD0530 at this concentration also decreased pY418 Src and pFAK Tyr861 levels. In addition, expression of E-cadherin was increased by AZD0530 in this cell line (Fig. 4B).
enhanced the inhibition of HNSCC invasion compared with either treatment alone, Matrigel invasion assays were done. HNSCC cell lines (1483, PCI-37B) were cultured in DMEM with 10% FBS. The IC$_{50}$ values of gefitinib for various cell lines used in this study were initially determined by 3-(4,5-dimethylthiazol-2-yl)-2,5-diphenyltetrazolium bromide and cell counts (Table 1). Cells were plated at a density of $1 \times 10^4$ per well in serum-free DMEM with the vehicle (DMSO), AZD0530 (1 μmol/L), gefitinib (at IC$_{50}$ value), or the combination of AZD0530 and gefitinib (both at IC$_{50}$ values) in the insert. The lower well contained DMEM with 10% FBS as a chemoattractant. As shown in Fig. 5A (1483) and Fig. 5B (PCI-37B), invasion of 1483 and PCI-37B cells treated with the combination of AZD0530 and gefitinib was decreased to 34.84% (±4.59%) and 28.39% (±4.71%) of the vehicle control, respectively, which was lower than AZD0530 alone [48.73 ± 3.30% (P = 0.034) and 51.94 ± 7.02% (P = 0.024), respectively] or gefitinib alone [71.51% ± 4.95% (P = 0.003) and 69.85% ± 3.82% (P < 0.001), respectively using ANOVA]. These results suggest that combined inhibition of Src and EGFR abrogates HNSCC invasion more than inhibition of either Src or EGFR alone.

**Combined inhibition of c-Src and EGFR abrogates growth of HNSCC cells.** Src kinases are involved in multiple signaling pathways that contribute to cell cycle progression and survival. Inhibition of Src kinases has been reported to inhibit tumor cell adhesion, migration, and invasion; however, their antiproliferative activity has been less consistently observed. AZD0530 was reported to have little effect on reducing the growth of breast cancer cells (37). Other Src kinase inhibitors, including dasatinib and AP23846, were reported to inhibit proliferation of HNSCC and lung cancer cells (35), as well as pancreatic adenocarcinoma cells (39). To determine whether AZD0530 inhibited proliferation of HNSCC cells, we did cell counting experiments in several HNSCC cell lines (1483, PCI-37B, and Cal-33) after treatment with AZD0530 and/or gefitinib (see Table 1 for IC$_{50}$ values of each compound in each cell line). These IC$_{50}$ values for gefitinib are comparable with values reported by others in HNSCC cells (40, 41). Cells were plated in
12-well plates at a density of $3 \times 10^4$ per well in DMEM with 10% FBS. After 24 hours, growth media were replaced with DMEM with 10% FBS containing DMSO, AZD0530 (at IC$_{50}$ value), gefitinib (at IC$_{50}$ value), or a combination of AZD0530 and gefitinib (both at IC$_{50}$ values; Fig. 7). Inhibition of Src activity by AZD0530 was confirmed, whereas gefitinib did not abrogate Src phosphorylation. Phosphorylation of MAPK was reduced by gefitinib or AZD0530 in two of the three cell lines examined with no apparent change in the setting of combined therapy. Akt phosphorylation was modestly reduced by treatment with gefitinib or AZD0530 with no apparent enhancement after the combined treatment. FAK phosphorylation was inhibited by AZD0530, but not by gefitinib. STAT5 phosphorylation was reduced by gefitinib and further reduced by combined treatment with AZD0530 in two of three cell lines examined. In the third cell line (PCI-37B), pSTAT5 was completely abrogated by AZD0530 (Fig. 7). These results suggest that reduction of pSTAT5 may be a marker of the combined effect of targeting EGFR and Src in HNSCC cells.

**Discussion**

The results of the present study suggest that increased c-Src expression and/or phosphorylation promotes the invasion and growth of HNSCC cells and that combined inhibition of c-Src and EGFR augments the inhibition of invasion and growth compared with blockade of either tyrosine kinase alone. These data provide a rationale for further investigation of the mechanism of combined EGFR and Src targeting in cancers that express increased levels of these proteins.

c-Src is a cellular homologue of v-Src, the oncogene product of the avian tumor virus, Rous sarcoma virus (42). c-Src is expressed at low levels in most cell types and, in the absence of appropriate extracellular stimuli, maintained in an inactive conformation through phosphorylation of a negative-regulatory domain at Tyr$^{530}$. The transforming activity of v-Src is much higher than that of c-Src due to the absence of the negative-regulatory COOH terminal domain and the presence of point mutations throughout the gene (43). A COOH terminally truncated c-Src that exhibits constitutive catalytic activity similar to v-Src has been detected in a small subset of colon and endometrial cancers (44, 45). Other studies, however, have failed to detect such mutations in malignant colon tumors (46–48), suggesting that mutations that lead to activation of c-Src are rare. c-Src activity in metastatic liver lesions has been reported to be higher than levels detected in primary colon cancers (49). In transitional cell carcinoma of the bladder, c-Src activity seemed to increase as superficial tumors invaded into muscle (50), implicating c-Src in tumor progression.

![Fig. 4. The effect of increasing doses of AZD0530 on expression and activation of c-Src and FAK in HNSCC cell lines. A, UM-22B, 1483, and PCI-37B cells were treated with AZD0530 (1-10^4 M) or DMSO for 2 h before lysis. Immunoblotting was done with pY418 c-Src antibody, anti-c-Src antibody, pFAK Tyr$^{Y861}$, and total FAK. B, Cal-33 cells were treated with increasing concentrations of AZD0530 (0.06-6 M) or DMSO for 2 h followed by immunoblotting for total and activated c-Src, E-cadherin, and pFAK Y861. The experiment was done thrice with similar results.]

**Table 1. IC$_{50}$ values for gefitinib and AZD0530 in HNSCC cell lines**

<table>
<thead>
<tr>
<th>SCCHN cell line</th>
<th>IC$_{50}$ gefitinib (nM)</th>
<th>IC$_{50}$ AZD0530 (nM)</th>
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<tbody>
<tr>
<td>1483</td>
<td>15</td>
<td>1</td>
</tr>
<tr>
<td>UM-22B</td>
<td>20</td>
<td>1</td>
</tr>
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<td>PCI-15B</td>
<td>10</td>
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</tr>
<tr>
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<td>1</td>
</tr>
<tr>
<td>Cal-33</td>
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Cancer Therapy: Preclinical

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There is little information on the expression and activation of c-Src in head and neck carcinogenesis. Increased expression of c-Src has been detected in areas of hyperproliferation in HNSCC, as well as premalignant mucosal lesions (19). To begin to determine the consequences of Src activation in HNSCC, we engineered cells to stably express a DA form of c-Src. DA c-Src HNSCC cells showed increased growth and invasion in vitro compared with vector-transfected control cells. Increased invasion by c-Src is consistent with previous reports using colon cancer cells (51, 52). Transfection of DA c-Src has been reported to result in increased mitosis, tumor growth, and colony formation in an in vivo model using breast cancer cells (53) and decreased transforming growth factor-α–induced apoptosis in hepatocellular carcinoma cells (54), consistent with our proliferation assay results (Fig. 3). Cancer cell migration is regulated by a variety of factors, including integrins, matrix-degrading enzymes, cell-cell adhesion molecules, and cell-cell communication. c-Src has been reported to mediate cancer cell invasion by several mechanisms, including FAK phosphorylation and loss of focal adhesions (55), R-Ras phosphorylation and subsequent inhibition of integrin activity and adhesion (56), decreased E-cadherin by tyrosine phosphorylation, ubiquitination, and endocytosis of E-cadherin (57), and/or decreased hyaluronic acid–dependent migration by interaction with CD44 (58). To this effect, we observed increased expression of E-cadherin in Cal-33 cells, with increasing doses of AZD0530, and a concomitant decrease in pFAK Tyr861 levels (Fig. 4B). pFAK Tyr861 levels also decreased with increasing doses of AZD0530 in PCI-37B, UM-22B, and 1483 treated cells (Fig. 4A).

The central role of c-Src in many signaling transduction pathways combined with the frequent overexpression of c-Src in human epithelial cancers makes Src an attractive target for cancer therapy. Preclinical strategies for targeting c-Src include DN mutants (17, 20), small inhibitory RNA (59), and Src kinase inhibitors. The pyrazolopyrimidines PP1 and PP2 have been used extensively in in vitro models of Src inhibition, although concentrations of up to 10 μmol/L are often necessary to achieve complete Src kinase inhibition in cell culture (60). High concentrations of these inhibitors often inhibit off-target kinases, including CSK and p38 MAPK, as well (61). Because of the nonspecific inhibition of other kinases, it has been hard to delineate Src-specific effects of these reagents in the absence of supporting data from DN c-Src, small inhibitory RNA, or gene knockout studies. A new generation of Src-specific inhibitors has been Food and Drug Administration–approved for selected...
hematologic malignancies (dasatinib) and/or is being tested in solid tumors (AZD0530 and dasatinib; refs. 35, 39, 62–64). Dasatinib was reported to inhibit migration and invasion of HNSCC cells and induce cell cycle arrest and apoptosis in some of the cell lines (35). This study also showed down-regulation of pSTAT5 in HNSCC cells after treatment with the Src inhibitor. Our finding of further reduction of pSTAT5 levels with dual EGFR/Src inhibition suggests that pSTAT5 may serve as a biomarker to identify patients or indicate therapeutic response. We reported previously that blockade of Src kinases using a second generation pyrrolopyrimidine compound, A419259, or a pyrido[2,3-d]pyrimidine derivative, PD180970, inhibited growth in HNSCC cells (20). In the present study, we used AZD0530, which blocks the ATP-binding site of Src kinases and is also an inhibitor of kinases with closely related structures, such as Abi (27). AZD0530 has been reported to inhibit the invasion of tamoxifen-resistant breast cancer cells at low concentrations (0.1 μmol/L) but only modestly reduced cell growth at higher concentrations (1 μmol/L; ref. 37). We found that Src and FAK activation in HNSCC cells was inhibited by 1 μmol/L AZD0530 in three of four cell lines examined. AZD0530 blocked the invasion of HNSCC cells at similar concentrations to that observed in breast cancer cells. However, HNSCC cells were more sensitive to the growth inhibitory effects of AZD0530 (Fig. 6). These results suggest that, whereas c-Src plays a central role in cancer invasion, the role of c-Src in mediating cell growth may depend upon the specific model under investigation.

Overexpression of EGFR and ligands in cancer tissue, the correlation between EGFR expression and poor clinical outcome, and the aberrant function of the EGFR network in cancer cells have implicated EGFR as a target for cancer therapy. EGFR has been shown to activate c-Src kinase through a variety of mechanisms, including the small GTPases Ras and Ral (65), and the recruitment of Shp2, which dephosphorylates the Csk-binding protein PAG, thereby preventing the access of Csk, a negative regulator of Src, to Src (66). Inhibition of EGFR has been reported to reduce Src activity to basal levels in colon cancer cell lines (67). We showed previously that EGFR-deficient murine embryonic fibroblasts showed decreased activation of c-Src after stimulation with gastrin-releasing peptide, where c-Src was shown to mediate the cleavage of EGFR proligand cleavage (17). In addition, overexpression of c-Src has reported to result in the accumulation of EGFR at the cell surface by promoting destruction of c-Cbl, which mediates EGFR ubiquitylation and sorting to endocytosis and degradation (68). In the present study, combined inhibition of EGFR and c-Src inhibited cell growth to a larger degree than treatment with a single inhibitor alone. These results suggest that the combined targeting of c-Src and EGFR may be a rational therapeutic approach in cancers that show increased EGFR and Src activation, including HNSCC.

**Disclosure of Potential Conflicts of Interest**

No potential conflicts of interest were disclosed.

**References**

9. Ang KK, Berkey BA, Xu T, et al. Impact of epidermal growth factor receptor expression on survival and