We hypothesized that inhibition of the FAS-mediated apoptosis pathway by FLICE-like inhibitory protein (c-FLIP) may contribute to oncogenesis in ALK⁺ anaplastic large-cell lymphoma (ALCL). Treatment with increasing concentrations of CH-11 (CD95/FAS agonistic antibody) had no effect on cell viability of 2 ALK⁺ ALCL cell lines, Karpas 299 and SU-DHL1, each expressing high levels of c-FLIP. However, inhibition of endogenous c-FLIP expression by specific c-FLIP siRNA in Karpas 299 and SU-DHL1 cells treated with CH-11 resulted in FAS-mediated cell death associated with increased annexin V binding, apoptotic morphology, and cleavage of caspase-8. In 26 ALK⁺ ALCL tumors, assessed for expression of DISC-associated proteins, CD95/FAS and c-FLIP were commonly expressed, in 23 (92%) of 25 and 21 (91%) of 23 tumors, respectively. By contrast, CD9SL/FASL was expressed in only 3 (12%) of 26 ALCL tumors, although it was strongly expressed by surrounding small reactive lymphocytes. Our findings suggest that overexpression of c-FLIP protects ALK⁺ ALCL cells from death-receptor–induced apoptosis and may contribute to ALCL pathogenesis.

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**Introduction**

Anaplastic large-cell lymphoma (ALCL) frequently carries the t(2;5)(p23;q35) or other 2p23 locus rearrangements that result in overexpression of anaplastic lymphoma kinase (ALK). The t(2;5), the most common abnormality, creates a novel fusion gene, npm-alk. Among other mechanisms, NPM-ALK is believed to mediate its oncogenic potential through activation of phosphatidylinositol 3-kinase (PI3K)/Akt and STAT3 signaling pathways resulting in downstream antiapoptotic signals.

The extrinsic apoptotic pathway is initiated by death surface receptors, a subgroup of the tumor necrosis factor receptor (TNFR) superfamily, that have a characteristic intracytoplasmic domain, designated the death domain (DD). Upon ligation, CD95 (FAS), the best characterized death surface receptor, oligomerizes at the cell membrane and recruits the adapter protein FADD (FAS-associated death domain protein) through DD-DD association. FADD, in turn, recruits procaspase-8 by its death effector domain (DED), initiating the formation of the death-inducing signaling complex (DISC). In the DISC, procaspase-8 molecules are located in close proximity and are autocatalytically processed to active caspase-8. In “type I” cells, death receptors induce strong caspase-8 activation, directly activating effector caspases, including caspase-3, to ensure apoptosis. In “type II” cells, low amounts of caspase-8 are activated, depending on a mitochondrial amplification mechanism through the cleavage of BID.

Death-receptor–induced apoptosis is inhibited by c-FLIP, a DED-containing protein with a nonfunctional caspase-like catalytic domain with antiapoptotic function in the DISC.

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**Study design**

**Cell lines**

Two ALK⁺ (Karpas 299, SU-DHL1) cell lines known to carry the t(2:5) were used. As controls, a CD30⁺ T-cell lymphoma cell line, Mac2a (a gift from Dr K. Elenitoba-Johnson, Salt Lake City, UT), a Hodgkin lymphoma cell line, L-1236 (purchased from DSMZ, Braunschweig, Germany), and a mantle cell lymphoma cell line, Mino (a gift from Dr R. Ford, Houston, TX) were also used. The cell lines were maintained according to methods reported. Karpas 299 and SU-DHL1 cells were treated with the PI3K inhibitor LY294002, and the JAK3 inhibitors, WHI-P131 and WHI-P154, at the indicated concentrations. Whole-cell lysates were prepared 24 or 48 hours following treatment. Karpas 299 and SU-DHL1 cells also were infected with the HA-tagged, constitutively active, myrAkt adenovirus at a multiplicity of infection (MOI) of 20, previously shown to significantly increase Ser473p-AKT levels in vitro.

**Induction and detection of apoptosis**

Each cell line (1 × 10⁶ cells/mL) was incubated with increasing concentrations of the anti-CD95/FAS agonistic CH11 antibody (Beckman Coulter, Inc, Brea, CA). Annexin V-FITC/PI was measured by flow cytometry.

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Inhibition of c-FLIP expression by siRNA

The sequences of c-FLIP short interference (si) RNA targeting the human c-FLIP gene product were purchased from Ambion (Austin, TX): GGAG-CUCCUGGAUUAUUtt (sense) and AAAAAUCCAGAAGGUCCGt (antisense). Transient transfection of Karpas 299 and SU-DHL1 cells was performed using the Nucleofector solution “T” (Amaxa Biosystems, Gaithersburg, MD). Approximately 2 × 10⁶ cells were transfected with 0, 5, and 10 μg c-FLIP siRNA using 100 μL T solution (Amaxa Biosystems) according to the manufacturer’s protocol. Cells were harvested at 48 hours following transfection and whole-cell lysates were prepared for Western blot analysis. In addition, Karpas 299 and SU-DHL1 cells (each 1 × 10⁶ cells/mL) were preincubated with 10 μg c-FLIP siRNA for 24 hours in 6-well plates and subsequently with 200 ng/mL CH11 (Beckman Coulter). Control transfections with the siRNA of 2 housekeeping genes, GAPDH and 4EBP1, were also performed.

Results and discussion

ALK+ ALCL cells are resistant to FAS-induced apoptosis

Induction of the extrinsic apoptotic pathway using an agonistic anti-CD95/FAS antibody demonstrated no cell death in both ALK+ ALCL cell lines (Figure 1A). In contrast, substantial apoptotic cell
death was observed after treatment of Mac2a and Mino cells with increasing concentrations of CH-11. Apoptotic death of Mac2a cells after CH-11 treatment was associated with cleavage of caspase-8 and down-regulation of c-FLIP (Figure S1, available on the Blood website; see the Supplemental Figures link at the top of the online article). These results are consistent with previously published data by Dirks et al \(^{23}\) who described resistance to CD95/FAS-induced apoptosis in ALK\(^+\) ALCL cells. They also assessed for FAS gene mutations as a possible underlying mechanism, but they did not identify mutations in 3 ALK\(^+\) ALCL cell lines, including Karpas 299. Another possibility would be inhibition of DISC function through overexpression of c-FLIP. In both ALK\(^+\) ALCL cell lines (Karpas 299, SU-DHL1), the long (c-FLIP\(_L\)) and short (c-FLIP\(_S\)) isoforms of c-FLIP were expressed (Figure S2). Of note, the short c-FLIP isoform, which has been shown to totally prevent caspase-8 cleavage, \(^{23}\) was expressed at a relatively higher level in ALK\(^+\) ALCL cells than in control cell lines.

**Specific inhibition of c-FLIP expression by siRNA induces CD95/FAS-mediated apoptosis in ALK\(^+\) ALCL**

We show here that a major inhibitor of DISC function, c-FLIP, appears to be responsible for resistance of ALK\(^+\) ALCL cells to death-receptor–induced apoptosis. Endogenous c-FLIP expression was completely inhibited when 10 \(\mu\)g siRNA was used (Figure 1B). This was associated with a slight increase in the number of apoptotic cells (Figure 1C-D) that may be due to the endogenous FASL expression (Figure S2). However, preconditioning of ALK\(^+\) ALCL cells with c-FLIP siRNA and treatment with CH-11 significantly induced apoptosis, associated with apoptotic morphology and cleavage of caspase-8 (Figure 1E-F). Therefore, inhibition of c-FLIP expression using c-FLIP siRNA sensitized ALK\(^+\) ALCL cells to FAS-induced apoptosis. In line with our data, 2 recent reports demonstrated sensitization to CD95/FAS-mediated cell death in Hodgkin lymphoma cell lines using a specific c-FLIP siRNA.\(^{15,16}\) However, additional factors contributing to protection of ALK\(^+\) ALCL cells from extrinsic apoptotic signals cannot be excluded.

**Expression of extrinsic apoptotic pathway proteins in ALK\(^+\) ALCL tumors**

Using a 10% cutoff, CD95/FAS and c-FLIP were overexpressed in 23 (92%) of 25 and 21 (91%) of 23 tumors, respectively (Figure 2A,C). By contrast, CD95L/FASL was expressed by the neoplastic cells in only 3 (12%) of 26 ALCL tumors (Figure 2B). However, FASL was always detected at high levels in the reactive small lymphocytes and endothelial cells, suggesting that the microenvironment of these tumors is capable of producing FASL. These results concur with previous findings reported by Sigel and Hsi.\(^{26}\) In a series of 10 ALCL cases (including 2 ALK\(^+\)), CD95/FAS was expressed in more than 90% of tumor cells in all cases, whereas CD95/FASL was expressed only in a subset of tumor cells.

The mechanisms underlying c-FLIP up-regulation in ALK\(^+\) ALCL cells most likely are complex. Although, it has been suggested that c-FLIP up-regulation depends on NF-\(\kappa\)B activation in Hodgkin lymphoma,\(^{15,16}\) recent evidence shows that NF-\(\kappa\)B is

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**Figure 2. c-FLIP overexpression in ALCL.** (A-C) Immunohistochemical detection of extrinsic apoptotic pathway proteins in reactive lymph node and ALK\(^+\) anaplastic large-cell lymphoma (ALCL) tumors. (A) CD95/FAS was weakly expressed in a subset of centroblasts within the germinal centers (GCs) of reactive lymph nodes (left). Strong cytoplasmic and membranous CD95/FAS expression was observed in most ALK\(^+\) ALCL tumors (right). (B) CD95L/FASL was not expressed in most ALK\(^+\) ALCL tumors (right). Infiltrating small reactive lymphocytes strongly expressed CD95L/FASL and served as internal positive controls in all tumor specimens. (C) c-FLIP expression was restricted to a subset of GC cells (left). Strong cytoplasmic expression for c-FLIP was observed in most ALK\(^+\) ALCL tumors (right). (D-E) c-FLIP up-regulation may result from activation of PI3K/Akt and JAK3/ALK oncogenic pathways. Immunohistochemistry: \(\times\) 200 original magnification (20 ×/0.75 NA objective; left panels) or \(\times\) 400 (40 ×/0.75 NA objective; right panels). Images were obtained with a BX51 Olympus microscope, a DP12 Olympus camera, and a universal semi-apochromat UPlanFI lens. (D, left panel) Karpas 299 and SU-DHL1 cells were treated with a PI3K inhibitor, LY294002, at concentrations of 0, 5, or 20 \(\mu\)g/mL. Whole-cell lysates were then prepared at 48 hours. Immunoblots showed that serine 473 phosphorylation of Akt is almost completely inhibited at a concentration of 20 \(\mu\)g/mL that is associated with a substantial decrease of c-FLIP levels. (D, right panel) Karpas 299 and SU-DHL1 cells were infected with the constitutively active, myrAkt adenovirus\(^{21}\) at an MOI of 20, which significantly increases Ser473pAkt levels in these cells. Expression of myrAkt was confirmed by Western blot analysis using a monoclonal antibody specific for the hemagglutinin (HA) tag. An adenovirus-\(\beta\)-Gal adenovirus construct expressing \(\beta\)-Gal served as a control in this experiment. Whole-cell lysates were prepared from control and infected cells 48 hours after infection. Immunoblots showed a dramatic increase of Akt phosphorylation, which was associated with an increase of c-FLIP, splice variant. (E) ALK\(^+\) ALCL cells were treated with 2 known JAK3 inhibitors, WHI-P131 and WHI-P154, at concentrations previously shown to inhibit JAK3 and ALK enzymatic activity.\(^ {25}\) Whole-cell lysates were prepared 24 hours following treatment. Immunoblots demonstrate that c-FLIP levels are decreased after treatment with WHI-P131 or WHI-P154 in a dose-dependent manner.
not active in ALK+ ALCL.27 Therefore, NF-kB–independent mechanisms may be involved. One possibility is that c-FLIP is up-regulated by the PI3K/Akt pathway,28 as Akt can be phosphorylated/activated by NPM-ALK.4,5 Here, we show that inhibition of PI3K/Akt down-regulates c-FLIP, and, inversely, forced expression of constitutively active Akt up-regulates c-FLIP. Indeed, we have shown that inhibition of JAK3 kinase activity, which has been shown to inhibit ALK activity, also down-regulates c-FLIP. Indeed, we have shown that inhibition of JAK3 kinase activity, which has been shown to inhibit ALK activity,25 also down-regulates c-FLIP (Figure 2E). Another possibility is that ALK or other kinases interacting with ALK, such as JAK3, up-regulate c-FLIP. Indeed, we have shown that inhibition of JAK3 kinase activity, which has been shown to inhibit ALK activity,25 also down-regulates c-FLIP (Figure 2E).

Taken together, our results suggest that ALK+ ALCL cells are resistant to CD95/FAS-induced cell death due to c-FLIP overexpression. Up-regulation of c-FLIP may be a downstream target of oncogenic pathways involved in ALCL pathogenesis, thus providing a novel therapeutic target in ALCL patients.

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References


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c-FLIP confers resistance to FAS-mediated apoptosis in anaplastic large-cell lymphoma

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