HIV and CXCR4 in a kiss of autophagic death

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AIDS is characterized by CD4+ T lymphocyte depletion, yet the mechanisms underlying this central aspect of HIV pathogenesis are still poorly understood. In this issue of the JCI, Espert et al. identify a mechanism by which the HIV envelope glycoprotein can induce death in uninfected CD4+ T cells (see the related article beginning on page 2161). The HIV envelope glycoprotein interacts with CXC chemokine receptor 4 to activate the lysosomal degradation pathway of autophagy, which is necessary for both apoptotic and non-apoptotic cell death.

Since the beginning of the AIDS epidemic in the 1980s, even before the HIV virus was identified, physicians and scientists recognized that a cardinal feature of AIDS was the depletion of CD4+ T lymphocytes. Yet nearly a quarter of a century later, our understanding of how CD4+ T cells are depleted in HIV-infected patients remains incomplete. CD4+ T cells are killed by direct HIV infection, but substantial numbers of uninfected CD4+ T cells also die in HIV-infected patients. The death of these cells is postulated to result from Fas-mediated activation–induced cell death and/or the stimulation of apoptosis in uninfected bystander cells by released or cell surface–expressed HIV gene products including accessory proteins (e.g., Tat, Vpr, Vpu, and Nef) and envelope proteins (reviewed in refs. 1–3).

In this issue of the JCI, Espert et al. describe an advance in understanding how the HIV envelope glycoprotein can kill uninfected CD4+ T lymphocytes (4). By coculturing effector cells that express the HIV envelope glycoprotein with target cells that express CD4 and CXC chemokine receptor 4 (CXCR4), they demonstrate that CXCR4 engagement by the HIV envelope glycoprotein activates a lysosomal degradation pathway known as autophagy. Based on studies with pharmacological and genetic autophagy inhibitors, this activation of autophagy appears necessary both for caspase-dependent, apoptotic death of bystander cells and for caspase-independent, nonapoptotic death, which is presumably directly due to autophagy (Figure 1).

The word autophagy is derived from Greek and means to eat (phagia) oneself (auto). It is an evolutionarily conserved process involving the dynamic rearrangement of subcellular membranes to sequester cytoplasm and organelles for delivery to the lysosome, where the sequestered cargo is degraded and recycled. Autophagy occurs at basal levels in most tissues and contributes to the routine turnover of cytoplasmic components, playing a housekeeping function that is believed to delay aging, protect against neurodegeneration, and potentially function in tumor suppression (5–7). Autophagy is rapidly upregulated in response to different forms of cellular stress. This induction of autophagy may help promote cell survival, either by purging the cell of damaged organelles, toxic metabolites, and intracellular pathogens or by generating the intracellular building blocks required to maintain vital functions during nutrient-limiting conditions (reviewed in ref. 8). However, when very high levels of autophagy are induced, autophagy may also promote cell death through excessive self-digestion and degradation of essential cellular constituents.

There is increasing evidence that complex interrelationships exist between autophagy and the apoptotic cell death pathway (reviewed in ref. 8). Several regulators of apoptosis activation also function as regulators of autophagy activation (e.g., TRAIL, FADD, DAPK, ceramide, class I PI3K/Akt signaling, and Bcl-2 family members). Previously, it has been shown that genetic inhibition of autophagy can activate apoptotic death in nutrient-starved mammalian cells (9), suggesting that autophagy activation can function to prevent apoptosis. Conversely, it has also been suggested that autophagy activation may lead to apoptosis (reviewed in ref. 8); this conclusion was supported by data using a pharmacological inhibitor of autophagy, 3-methyladenine (3-MA), a nucleotide derivative that blocks class III PI3K activity. However, 3-MA can inhibit kinases other than class III PI3K (10), some of which may independently affect death signaling as well as inhibit the mitochondrial permeability transition (11). Now Espert et al. demonstrate that short interfering RNAs specific for 2 different autophagy execution genes (bclin 1 and atg7) can completely...
A - CXCR4-utilizing HIV variants only appear in approximately 50% of the HIV-infected patients that develop AIDS (reviewed in ref. 16), suggesting that CXCR4-independent mechanisms must also exist for bystander CD4+ T cell killing. The other major chemokine receptor used as a coreceptor for HIV entry, CCR5 chemokine receptor 5 (CCR5), has also been shown to be involved in mediating apoptosis triggered by CCR5-specific HIV envelope glycoproteins, although it is unclear whether this is an important mechanism for bystander CD4+ T cell death during infection with CCR5-specific viruses (reviewed in ref. 2). Thus, it will be of interest to determine whether engagement of CCR5 or other chemokine receptors by HIV envelope glycoproteins also trigger autophagy-dependent cell death in CD4+ T cells.

The activation of autophagy by HIV envelope glycoprotein engagement of CXCR4 may have important implications for understanding how viral glycoproteins subvert the normal host immune response. For example, the natural ligand for the CXCR4 receptor is stromal cell–derived factor 1 (SDF-1), and this chemokine normally functions to induce migration of CXCR4-expressing T cells to extravillous trophoblasts and to support T cell homing and development. CXCR4-specific envelope protein-induced autophagy and cell death in uninfected, CXCR4-expressing CD4+ T cells. However, it is not yet known whether a similar phenomenon occurs in the context of HIV infection in vivo and contributes to the progressive CD4+ T cell depletion that occurs in patients with AIDS. If this phenomenon does occur in vivo, it could potentially explain the more rapid decline in CD4+ T cell counts that generally occurs in patients with CXCR4-utilizing HIV variants (15). Yet CXCR4-utilizing HIV variants only appear in approximately 50% of the HIV-infected patients that develop AIDS (reviewed in ref. 16), suggesting that CXCR4-independent mechanisms must also exist for bystander CD4+ T cell killing. The other major chemokine receptor used as a coreceptor for HIV entry, CCR5 chemokine receptor 5 (CCR5), has also been shown to be involved in mediating apoptosis triggered by CCR5-specific HIV envelope glycoproteins, although it is unclear whether this is an important mechanism for bystander CD4+ T cell death during infection with CCR5-specific viruses (reviewed in ref. 2). Thus, it will be of interest to determine whether engagement of CCR5 or other chemokine receptors by HIV envelope glycoproteins also trigger autophagy-dependent cell death in CD4+ T cells.

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lymphoid tissues, not to induce autophagy (reviewed in ref. 17). Indeed, Espert et al. noted that SDF-1 was unable to trigger autophagy in their assays (4), indicating that the binding of HIV envelope glycoproteins to CXCR4 induces distinct intracellular signaling events compared with the natural ligand (Figure 1). These findings raise the possibility that viral proteins may selectively transduce signals through chemokine receptors that redirect the target cell away from its normal function and toward a cell suicide program driven by autophagy activation.

Conclusion
Espert et al. (4) report a very intriguing observation, namely that the HIV envelope glycoprotein induces CXCR4-dependent autophagy of uninfected lymphocytes, which is required for both caspase-dependent, apoptotic cell death and caspase-independent, nonapoptotic cell death. This work eloquently establishes that autophagy can function upstream of apoptosis in cell death signaling, that a viral envelope glycoprotein can trigger autophagy-dependent bystander cell death by binding to a cell surface receptor, and that a chemokine receptor can activate an autophagy-dependent death program in response to engagement by a viral protein. Future studies will be needed to determine whether the HIV envelope glycoprotein mediates autophagy-dependent cell death in bystander CXCR4-expressing CD4+ lymphocytes in HIV-infected patients and the relative contribution of this process to the progressive decline in numbers of CD4+ T cells in patients with AIDS.

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Evolution of the concept of costimulation: positive and negative costimulatory signals
In the early 1970s, Bretscher and Cohn proposed the 2-signal model for lymphocyte, specifically B cell, activation (1). Lafferty and colleagues later extended this model to T cell activation (2, 3). Realization that efficient T cell activation requires 2 signals (first, signal 1, an antigen-specific signal mediated via the TCR; second, signal 2, a noncognate costimulatory signal) led to the search for the costimulatory signal and identification of the CD28-B7 pathway in the early 1990s (4, 5).

Soon after the discovery of the CD28-B7 positive costimulatory pathway, it became apparent that CTL-associated antigen 4 (CTLA-4), a second inducible receptor that is homologous to CD28 and binds with higher affinity to B7-1 and B7-2, could function as a negative regulator of T cell activation (6, 7). CTLA-4 is also constitutively expressed on Tregs (8) and is important for their function (9–11) and generation (12, 13) while CD28 signaling is critical for Treg homeo-