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Consensus nomenclature for CD8$^+$ T cell phenotypes in cancer

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Whereas preclinical investigations and clinical studies have established that CD8$^+$ T cells can profoundly affect cancer progression, the underlying mechanisms are still elusive. Challenging the prevalent view that the beneficial effect of CD8$^+$ T cells in cancer is solely attributable to their cytotoxic activity, several reports have indicated that the ability of CD8$^+$ T cells to promote tumor regression is dependent on their cytokine secretion profile and their ability to self-renew. Evidence has also shown that the tumor microenvironment can disarm CD8$^+$ T cell immunity, leading to the emergence of dysfunctional CD8$^+$ T cells. The existence of different types of CD8$^+$ T cells in cancer calls for a more precise definition of the CD8$^+$ T cell immune phenotypes in cancer and the abandonment of the generic terms "pro-tumor" and "antitumor." Based on recent studies investigating the functions of CD8$^+$ T cells in cancer, we here propose some guidelines to precisely define the functional states of CD8$^+$ T cells in cancer.

Introduction: The Relevance of CD8$^+$ T Cells in Cancer

CD8$^+$ T cells are essential for clearing viral, protozoan, and intracellular bacterial infections.[1] Multiple lines of evidence show that CD8$^+$ T cells are also a key component of antitumor immunity. Initial studies in preclinical cancer models showed that CD8$^+$ T cells have a role in the prevention of tumor growth. Uyttenhove et al. showed that escape of P815 mastocytoma was due to loss of distinct CD8$^+$ T cell specificities[2] and Nakayama and Uenaka showed that antibodies against CD8$^+$ effectively blocked the spontaneous rejection of transplantable tumors.[3] Shankaran et al. and Smyth et al. later showed that adaptive immune responses were essential to prevent growth of mutagen-induced spontaneous tumors.[4,5] Interestingly, Shankaran et al. further reported that TAP1-transfected transplantable sarcomas were eliminated in wild-type mice in a CD8$^+$ T cell dependent-manner, suggesting that high expression of tumor antigens could drive activation of anticancer CD8$^+$ T cell responses.[4] Subsequent work from Koebel et al. showed that during the equilibrium phase of cancer growth, where cancer cells persist but are kept in check by the immune system,[6] depletion of CD8$^+$ T cells drives cancer cell growth, underscoring the importance of CD8$^+$ T cells in controlling cancer growth over long time periods.[7]

CD8$^+$ T cells have also been shown to be essential effector cells in the context of anticancer therapies. Depletion of CD8$^+$ T cells has been shown to abrogate the anticancer efficacy of oxaliplatin and doxorubicin against EL4 thymoma and MCA2 fibrosarcoma tumors, respectively.[8,9] Similarly, the therapeutic effect of local radiotherapy in melanoma, of interferon therapy in leukemia, and of bacille Calmette-Guerin therapy in bladder cancer is abrogated in the absence of CD8$^+$ T cells.[10-12] Altogether, these results establish that CD8$^+$ T cells can control spontaneous and carcinogen-induced tumor growth, invasiveness of transplantable cell lines as well as the therapeutic efficacy of some anticancer treatments.

In line with this substantial amount of preclinical work, it has been established in human cancers that CD8$^+$ T cell infiltrates can predict patients' survival. While in kidney cancer CD8$^+$ T cell infiltrates have been associated with worse outcome and with higher tumor grade,[13,14] they are linked to a better clinical outcome in the vast majority of other cancer types. In ovarian cancer, the presence of CD3 T cell infiltrates have been shown to correlate with improved survival rates.[15] In colon cancer, tumors without signs of metastatic invasion exhibit increased numbers of effector-memory CD8$^+$ T cells, thereby indicating that the presence of effector-memory CD8$^+$ T cells in the tumor microenvironment correlates with a better prognosis.[16] These findings were subsequently confirmed in other cohorts and an international consortium is currently evaluating the possible utilization of immune infiltrate data to predict patient survival in routine clinical settings.[17,18] The favorable prognostic value of CD8$^+$ T cell infiltrates has also been documented in other cancer types, such as breast cancer

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and epithelial ovarian cancer.[19,20] These findings suggest that, in humans, even in situations when tumors are detectable, $CD8^+$ T cells can control tumor progression. The clinical relevance of $CD8^+$ T cells in human cancer is further underscored by recent studies in breast cancer patients showing that the combination of high $CD8^+$ and low FOXP3 cell infiltrates after chemotherapy was significantly associated with favorable clinical responses.[21] These results were confirmed in two other studies, where $CD8^+$ tumor infiltrating T cells were found to be an independent predictive factor for pathological complete response after anthracycline or anthracycline-taxane-based chemotherapy.[9,22] Collectively, these preclinical and clinical observations indicate that $CD8^+$ T cells should not only be contemplated as a putative therapeutic tool but also as a biomarker to monitor the efficacy of cytotoxic chemotherapy. However, recent data also indicate that intra-tumoral $CD8^+$ T cells often lose their effector functions and exhibit a dysfunctional state. Accordingly, the terms "antitumor" and "pro-tumor" have been used in the literature to describe $CD8^+$ T cells in cancer. Given the advances in our knowledge of $CD8^+$ T cell phenotypes in cancer, these terms are clearly an oversimplification. Here, we discuss the different functional states of $CD8^+$ T cells in cancer and propose some guidelines for more accurate designation of $CD8^+$ T cells that exhibit different functional phenotypes.

$CD8^+$ Effector T Cells in Cancer

Naïve $CD8^+$ T cells that undergo priming *in vivo* in the presence of helper factors produced by $CD4^+$ T cells differentiate into effector T cells that express high levels of perforin and granzymes.[23,24] The coordinated delivery of these cytotoxic molecules to cancer cells can drive caspase activation and ultimately cell death[23,25-27] (**Fig. 1a**). Given the demonstrated potential of $CD8^+$ T cells to kill cancer cells, $CD8^+$ T cells are often refered to as cytotoxic T lymphocytes (CTLs). Several different methods can be employed to assess $CD8^+$ T cell cytotoxicity: direct measurement of target cell killing (for example by the chromium 51 release (^{51}Cr) assay[28]), flow cytometry based or ELISPOT measurement of granzyme B, a component of lytic granules in $CD8^+$ T cells,[29,30] and detection of the expression of CD107a, which is present on the cell surface of degranulating $CD8^+$ T cells. While the individual merits of these different methods have been debated, they have all been used to demonstrate CTL activity in cancer. Using quantification of CD107a, Rubio et al. showed that tumor-cytolytic T cells could be elicited in patients after vaccination and that tumor cell killing is associated with the ability of $CD8^+$ T cells to recognize their targets.[31] Using a ^{51}Cr release assay, Takeshima et al. showed that in tumor-bearing mice local radiotherapy could elicit cytotoxic tumor-specific $CD8^+$ T cells that prevent tumor growth.[32] Importantly, they further demonstrated the importance of $CD8^+$ T cells in mediating tumor regression following radiotherapy *in vivo* by using a neutralizing $CD8^+$ antibody. This key experiment, which was replicated in other studies,[10] was essential because the detection of activated or even antigen-specific cytotoxic T cells in *ex vivo*/*in vitro* assays does not necessarily ensure that $CD8^+$ T cells drive tumor regression *in vivo*.

$CD8^+$ T cells can also kill tumors via the Fas/Fas ligand pathway. Indeed, it has been proposed that FasL-driven $CD8^+$ T cell killing could be essential for the elimination of large and/or disseminated tumors.[33-35] However, it should be noted that tumors can lose Fas expression or develop mutations in the cell death pathway engaged by FasL, thus developing resistance to FasL/Fas-mediated $CD8^+$ T cell cytotoxicity. Other mechanisms by which tumors can resist $CD8^+$ T cell cytotoxicity are increased expression of anti-apoptotic molecules such as Bcl^-2, Bcl^-xl, and Mcl^-1 and changes in components of the cytoskeleton that impair the formation of stable immunological synapses between cytotoxic $CD8^+$ T cells and tumor cells.[36,37]

Strategies have also been developed to assess CTL activity *in vivo*. For this, the selective elimination of adoptively transferred carboxyfluorescein diacetate succinimidyl ester (CFSE)-labeled target cells bearing a specific $CD8^+$ T cell peptide has been examined in preclinical models.[38] While this technique has the major advantage of assessing $CD8^+$ T cell cytotoxicity *in vivo*, it does not inform as to the killing mechanism employed nor does it allow for visualization of the killing process. In regards to the latter, the development of intra-vital imaging represents a major advance in monitoring T cell anticancer functions *in vivo* in mice at the single-cell level. Using this technology, the group of Amigorena has found that activated cytotoxic $CD8^+$ T cells can infiltrate tumors and arrest in close contact to and kill tumor cells provided that the tumor cells express cognate antigen.[39] Using a similar methodology, Breart et al. found that in contrast to *in vitro* cytotoxic assays where tumor cell death occurs within minutes after incubation with cytotoxic T cells, the *in vivo* destruction of one tumor cell by a cytotoxic T lymphocyte in the tumor bed took on average 6 h, possibly explaining the limited ability of $CD8^+$ T cells to eradicate established tumors.[40]

While the cytotoxicity of $CD8^+$ T cells against tumor cells has been a major focus, it is important to note that some studies suggest that direct tumor cell killing may not be the major or only mechanism responsible for tumor regression. It has been shown that $CD8^+$ T cells can also recognize tumor antigens processed by the stroma[41] and studies using longitudinal confocal microscopy imaging have shown that vessel regression occurs immediately following $CD8^+$ T cell entry from the blood stream into the tumor.[42] Thus, cytotoxicity against tumor stroma may also be a major mechanism of tumor regression.

Although much attention has been given to the cytotoxic function of $CD8^+$ T cells, it is not the sole mechanism responsible for the anticancer activity of $CD8^+$ T cells. Activated $CD8^+$ T cells also secrete cytokines like TNFα and IFNγ, which can induce cancer cell senescence and play essential roles in the control of anticancer immune responses and tumor growth[43] (**Fig. 1a**). IFNγ has indeed been shown to be critical for cancer immunosurveillance and its secretion by $CD8^+$ T cells can enhance antigen presentation, the antitumor functions of

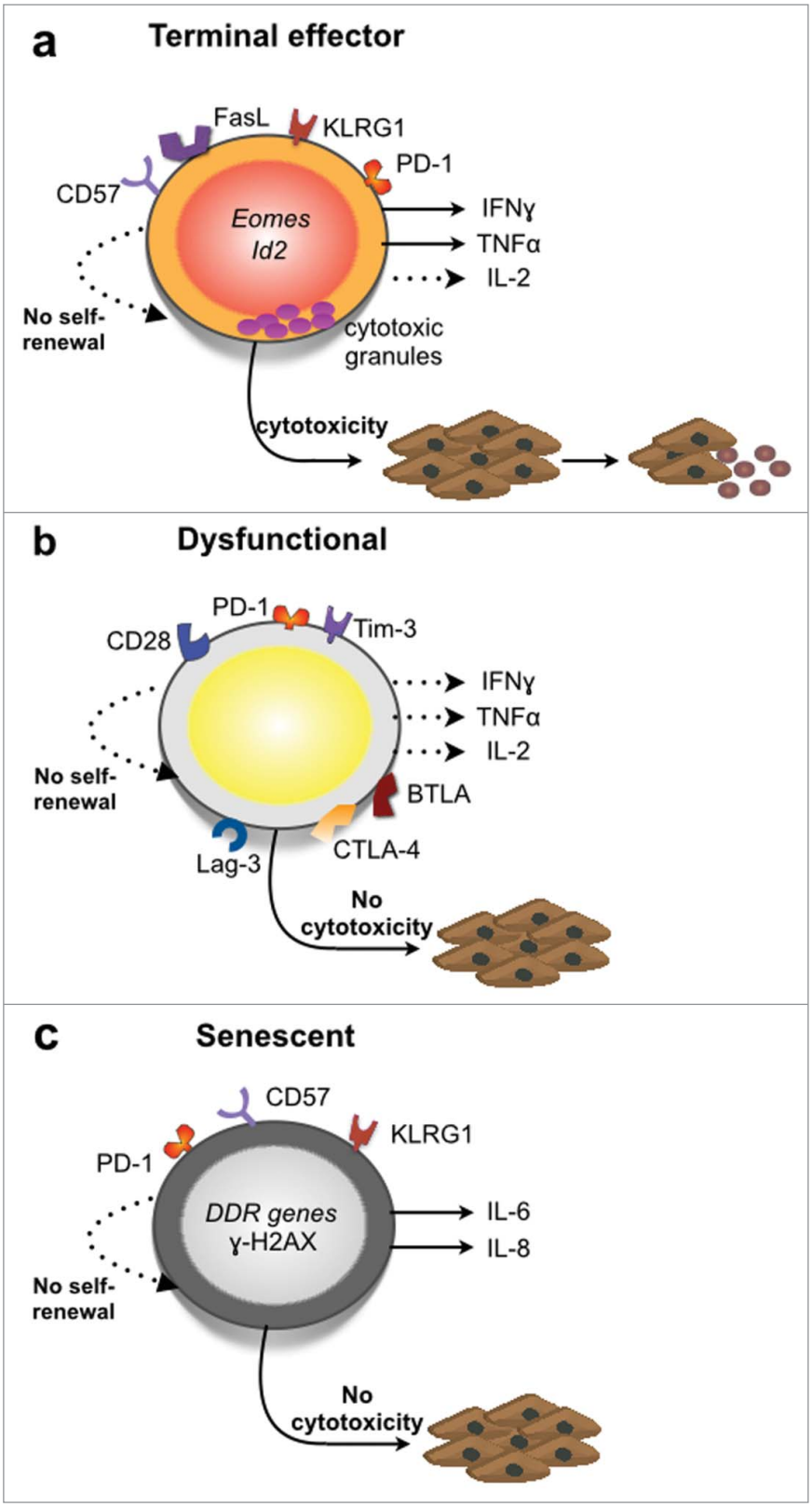

Figure 1. CD8$^+$ T cell phenotypes in the tumor microenvironment. (**a**) Effector CD8$^+$ T cells that undergo terminal differentiation are characterized by low IL-2, strong IFNγ and TNFα release as well as high expression levels of the transcription factors *Eomes* and *Id2*.[83–85] They do not express the surface markers CD62L, CCR7, CD27 but express killer cell lectin-like receptor G1 (KLRG-1) and PD-1.[63,86–89] While terminal effector CD8$^+$ T cells exhibit strong cytolytic functions *in vitro*, their anticancer activity *in vivo* is limited because of their inability to self-renew compared to stem-cell like memory CD8$^+$ T cells.[78,90,91] (**b**) Dysfunctional CD8$^+$ T cells are characterized by cocomittant expression of two or more inhibitory receptors such as CTLA-4, PD-1, Lag-3, Tim-3, and BTLA.[65,92,93] These cells exhibit defects in cytotoxicity, proliferative capacity, and secretion of pro-inflammatory cyotkines: IL-2, TNFα and IFNγ.[55,56,94] (**c**) Senescent CD8$^+$ T cells express killer cell lectin-like receptor G1 (KLRG-1) and CD57 but not CD27 or CD28.[87,95] They are characterized by short telomeres, poor proliferative capacity and activation of DNA damage response (DDR) genes.[66,68,95,96] These cells were also shown to express PD-1 in chronic lymphocytic leukemia patients.[95] Senescent CD8$^+$ T cells lack cytotoxicity,[96] and were shown to express the proinflammatory mediators *Il6* and *Il8* in lung cancer tissue.[68]

macrophages, and limit tumor angiogenesis.[44-46] CD8$^+$ T cell-derived IFNγ was further shown to be critical for the anticancer efficacy of chemotherapeutic drugs such as doxorubicin and oxaliplatin.[8] Importantly, the ability of these drugs to prevent tumor outgrowth was not compromised in perforin-deficient mice, suggesting that in this system CD8$^+$ T cells do not prevent tumor growth through direct cytotoxic activity. Accordingly, immunization of mice with chemotherapy-treated dying tumor cells failed to elicit CD8$^+$ T cell cytotoxicity but instead induced their secretion of IFNγ. Thus, in some contexts the ability of CD8 T cells to produce IFNγ may be more critical than their cytolytic function for antitumor efficacy.[8] These observations are in line with previous studies that identified IFNγ-dependent anti-angiogenesis as a general mechanism involved in tumor rejection by CD8$^+$ T cell effectors.[47]

Altogether, these observations underscore that the "antitumor" activity of effector CD8$^+$ T cells in tumor tissue can be ascribed to both their direct cytolytic activity and their cytokine secretion. Indeed, poly-functional CD8$^+$ T cells that exhibit cytotoxicity along with production of TNFα and IFNγ may be the most robust antitumor effectors. In this regard, it is also important to note that the efficacy of effector CD8$^+$ T cells in the tumor microenvironment may be limited as they undergo terminal differentiation and lose their ability to self-renew. The

"antitumor" potential of $CD8^+$ T cells that retain self-renewing capacity is discussed below.

Cancer-Driven $CD8^+$ T Cell Dysfunction

Although effector $CD8^+$ T cells can be found in the tumor microenvironment, it is also well established that tumors can drive $CD8^+$ T cell dysfunction. In the literature, the terms "anergic" and "exhausted" have both been used to describe dysfunctional $CD8^+$ T cells. Whether the $CD8^+$ T cells in cancer are anergic or exhausted has been a matter of debate. Here, we will discuss the use of these terms to describe dysfunctional $CD8^+$ T cells in cancer.

Anergy typically refers to a general state of diminished function of a given immune response. In the 1980s, the term was applied to T cells induced into a state of non-responsiveness *in vitro* upon engagement of the T cell receptor (Signal 1) in the absence of a costimulatory signal (Signal 2). In a number of *in vivo* settings, such as tolerance induction by i.v. injection of antigens without adjuvants, it was hypothesized that T cell unresponsiveness was similarly induced by antigen recognition without appropriate co-stimulatory signals.[48] Anergic T cells fail to proliferate and produce effector cytokines in response to subsequent stimulation. T cell anergy is believed to be operative in cancer given that tumors often poorly express co-stimulatory molecules such as B7-1/B7-2, that dendritic cells present in tumor tissue express low MHC and low B7-1/B7-2 but high PD-L1 (B7-H1),[49] and that myeloid-derived suppressor cells (MDSC) and tumor-associated macrophages (TAM) contribute to sub-optimal antigen presentation in the tumor environment.[50] Moreover, MDSCs and TAMs can produce arginase-1 and TGF-β and drive oxidative stress, all of which drive suppression of $CD8^+$ T cell responses.[51]

The term "exhaustion" comes from the study of the $CD8^+$ T cell response to chronic viral infections in mouse models where antigen is not cleared despite ongoing stimulation. There is also an evidence for virus-specific T cell "exhaustion" in humans in the setting of chronic HCV and HIV. Similar to anergic T cells, "exhausted" T cells exhibit defective responses to antigen stimulation; however, unlike anergy which develops as a result of a sub-optimal first encounter of T cells with cognate antigen, exhaustion develops progressively as a result of chronic stimulation of T cells in the face of high antigen burden.[52] Indeed, the T cells that develop an "exhausted" phenotype are those that undergo robust activation in the acute phase of the anti-viral response.

"Exhausted" $CD8^+$ T cells express high levels of co-inhibitory receptors such as PD-1, Lag-3, CD244, CD160, and Tim-3, and it has been shown that interfering with the signaling through one or more of these receptors can improve anti-virus $CD8^+$ T cell responses.[53,54] $CD8^+$ T cells that express inhibitory molecules and exhibit severe functional deficits have also been described in cancer[55-59] (**Fig. 1b**). These observations have led to the widespread use of the term "exhaustion" to describe the dysfunctional $CD8^+$ T cells in cancer. However, whether the dysfunctional $CD8^+$ T cells observed in cancer are truly analogous to those that arise in chronic viral infection is an open question. Resolution of this issue awaits elucidation of the molecular programs specifically associated with dysfunctional T cells in cancer. These studies are currently at an early stage. An initial study of the dysfunctional $CD8^+$ T cells from the tumor-infiltrated lymph nodes of melanoma patients indicates that the gene profile of these cells is significantly enriched for genes identified in exhausted LCMV-specific murine $CD8^+$ T cells; however, these cells fail to upregulate Batf, a key driver of T cell exhaustion in HIV infection.[57]

Moreover, it has recently been suggested that "exhaustion" is a misnomer as "exhausted" cells are not completely devoid of function as the term "exhaustion" implies. Rather these cells exhibit an attenuated response that is optimized for minimizing tissue damage while still preserving some level of response against abnormal cells (virally infected or cancerous).[60] Indeed, a key function of co-inhibitory receptor expression on highly active T cells is to contract ongoing T cell responses in order to restore immune homeostasis and prevent immunopathology. Unfortunately, tumors have taken advantage of this mechanism to dampen antitumor T cell responses.

At this juncture, we recommend against ascribing the $CD8^+$ T cells in cancer as either "anergic" or "exhausted." This terminology is not useful as these states have been defined and largely studied in other T cell types, such as $CD4^+$ T cells, or in disease conditions that differ significantly from cancer, namely chronic viral infection. We recommend that the term dysfunctional instead be used to describe the poorly functional $CD8^+$ T cells in cancer.[61] We further caution against ascribing cells as dysfunctional based on expression of co-inhibitory receptors alone as these molecules are also found on effector T cells that retain functional properties.[62] Indeed, expression of these inhibitory receptors could also reflect a state of previous activation of $CD8^+$ T cells indicating that expression of these receptors may identify antitumor specific T cells associated with a good prognosis[63,64] . Dysfunctional $CD8^+$ T cells should be defined as cells that exhibit defects in proliferation, lack of inflammatory cytokine production and/or cytotoxic functions, together with expression of one or more co-inhibitory receptors (**Fig. 1b**).

It is important to note that $CD8^+$ T cell dysfunction in the tumor microenvironment is believed to be reversible, at least to some extent. In pre-clinical cancer models, blockade of signaling through CTLA-4, PD-1, Tim-3, and Lag-3 have been shown to improve $CD8^+$ T cell responses (reviewed in [65]). Accordingly, the current success of strategies that interfere with signaling through the PD-1 inhibitory receptor in the clinic is believed, at least in part, to be due to the ability of PD-1 blockade to re-invigorate $CD8^+$ T cell responses.

$CD8^+$ T Cell Senescence in Cancer

Senescent $CD8^+$ T cell phenotypes can also arise in the tumor microenvironment. Senescence refers to an irreversible state of growth arrest that develops in cells upon repeated cellular division, termed replicative senescence, or in response to DNA

damage. General characteristics of senescent cells include: short telomeres, irreversible cell cycle-arrest, activation of DNA damage response (DDR) genes, robust secretion of factors that constitute the senescence-associated secretory phenotype (SASP), and accumulation of senescence associated heterochromatin foci (SAHF).[66] Specific cell surface markers ascribed to senescent T cells are loss of CD28 and CD27 and high expression of CD57 and KLRG-1 (**Fig. 1c**).

While senescence has historically been associated with aging, it is now recognized that replicative senescence also develops in the context of chronic antigen stimulation, such as that which occurs in cancer. Indeed, it has been shown that culture of tumor cells with normal healthy human T cells in low tumor to T cell ratios can induce a phenotype consistent with T cell senescence *in vitro*.[67] These cells exhibit decreased CD28 and CD27 expression along with concomitant up-regulation of γH2AX (H2A histone family member X) and ATM (ataxia telangiectasia mutated), both of which are induced as part of the DDR to double strand DNA breaks (**Fig. 1c**). A recent study further reported the presence of $CD8^+$ T cells that exhibit characteristics of senescence *in vivo* in human lung cancer tissue.[68] These cells are $CD28^-CD57^+$ and exhibit accumulation of heterochromatin protein-1 gamma foci, a component of SAHF.

Although senescent T cells are irreversibly cell-cycle arrested, it is important to note that they are not completely devoid of function. The senescent $CD8^+$ T cells found in lung cancer tissue produce IL-6 and IL-8, two hallmark SASP factors.[68] These two features distinguish senescent $CD8^+$ T cells from dysfunctional $CD8^+$ T cells (**Fig. 1b and c**) as the dysfunctional T cells are not irreversibly cell-cycle arrested they exhibit severely impaired production of pro-inflammatory cytokines and other effector molecules.

The two SASP factors that are reported to be expressed by senescent $CD8^+$ T cells, IL-6 and IL-8, are both pro-inflammatory cytokines. IL-6 can suppress regulatory T cell function (Treg)[69] and promote the differentiation of IL-17-producing Th17 cells.[70] The dampening of Treg function could benefit antitumor immunity by relieving an important mechanism of immune suppression in tumor tissue. However, the outcome of promotion of Th17 cells in tumor tissue is less clear as both "pro-tumor" and "antitumor" properties for Th17 cells have been described.[71] Notwithstanding how IL-6 may shape antitumor T cell responses, IL-6 can promote tumorigenesis through its effects in driving cellular proliferation, promoting cell survival by delivering anti-apoptotic signals, and augmenting MDSC suppressive functions.[72,73] Indeed, high levels of IL-6 have been associated with multiple cancers and are associated with poor prognosis.[74] IL-8 also exhibits pleiotropic tumor promoting effects. It can promote angiogenesis, cancer cell survival, proliferation, migration, and resistance to chemotherapy.[75] Thus, by virtue of their production of IL-6 and IL-8 senescent $CD8^+$ T cells could be considered "pro-tumor."

It is also important to note that terminal effector $CD8^+$ T cells can also exhibit loss of CD28 and upregulation of KLRG-1. Moreover, vaccine-induced $CD8^+$ T cells with optimal antitumor effector function have been noted to express high levels of KLRG-1.[76] Thus, senescent phenotype cannot be ascribed solely on the basis of loss of CD28 and expression of KLRG1. Senescent cells must further exhibit SAHF and activation of DDR genes (**Fig. 1c**).

Stem-Cell Like Memory $CD8^+$ T Cells

Terminal effector $CD8^+$ T cells limit tumor outgrowth. However, these cells can become dysfunctional or senescent in the tumor microenvironment. Recent studies that examine the efficacy of *ex vivo* generated $CD8^+$ T cells on tumor clearance after adoptive transfer into tumor-bearing hosts show that terminally differentiated effector $CD8^+$ T cells are ineffective at eliminating tumors *in vivo* compared to less differentiated T cells[77,78] (**Figs. 1a and 2**). This occurs in spite of their higher secretion of IFNγ and cytolytic activity. Instead, it has been suggested that $CD8^+$ T cells that share properties with naïve T cells such as CCR7 and CD62L expression and have the ability to self-renew are more potent for fighting tumors (**Fig. 2**). Because of their ability to self-renew and persist for long periods of time, these $CD8^+$ T cells have been termed stem-cell like memory T cells. Unfortunately, in contrast to terminal effector $CD8^+$ T cells, stem-cell like memory $CD8^+$ T cells are predominantly found in lymphoid tissue and not in the tumor microenvironment.

It is well known that the omnipotency of naïve T cells is progressively lost with T cell differentiation to memory and effector T cells. Among antigen-experienced T cells, the stem-cell like memory T cells are the ones with the highest potency, producing progeny for both immediate immunity and its long-term maintenance, based on self-renewal. It is likely that tumor-antigen specific effector T cells depend on continuous differentiation from self-renewing memory T cells. Therefore, it remains a major aim to develop methods inducing self-renewing T cells *in vitro* for adoptive transfer, or *in vivo* by active immunization. In this regard, the recent identification of IL-7 and IL-15 as molecular signals guiding human naive T lymphocytes to differentiate into stem-cell like memory $CD8^+$ T cells *in vitro* provides impetus to investigate their anticancer potential in clinical trials.[79,80] Progress in basic research, bioengineering, and therapy development will likely further exploit the potential of T cell stemness, as a fundamental basis of robust and long-term T cell responses including the capability to home to tumors and exert effector functions therein.

$CD8^+$ T Cells as Regulatory Cells in Cancer?

The existence of several types of $CD8^+$ T cells with regulatory or suppressive properties in cancer has been proposed. These include: $CD8^+$ $CD28^-$, $CD8^+$ $CD25^+$, $CD8^+$ $CD122^+$, and $CD8^+$ $IL\text{-}10^+$ T cells.[81,82] At present, there seems to be no consensus in the field as to whether these are overlapping or dissimilar subsets and, moreover, whether these are truly distinct from other cell types that express some of the same surface markers. For these reasons, this potential class of

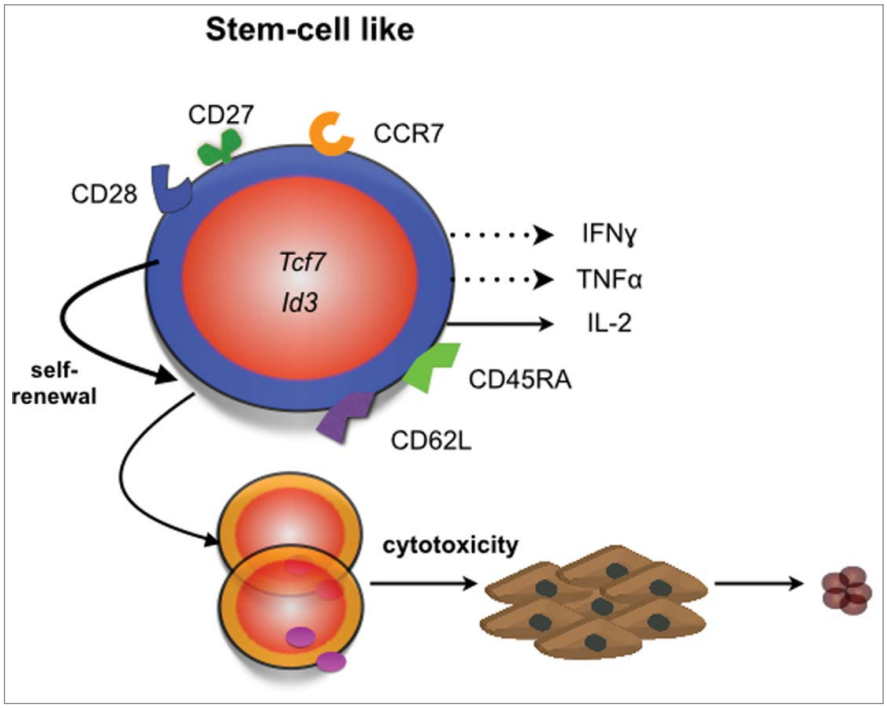

Figure 2. Features of stem-cell like CD8$^+$ T cells. Stem-cell like memory CD8$^+$ T cells share many phenotypic features with naïve T cells (reviewed in [97]). They typically express the CD45RA phosphatase, the lymph node homing molecules CCR7 and CD62L as well as the costimulatory receptors CD27 and CD28.[77,98] These cells express the transcription factors *Id3*[77] and *Tcf7*,[91] secrete IL-2 and low levels of TNFα or IFNγ. These cells also have the ability to self-renew and exhibit potent anti-cancer responses *in vivo*.[78,90]

CD8$^+$ T cells will not be further discussed here.

Conclusion

Our understanding of the CD8$^+$ phenotypes that arise in cancer necessitates that we move beyond the simplified nomenclature of "pro-tumor" vs. "antitumor" T cells. We, and others, have now identified stem cell-like, terminal effector, dysfunctional, or senescent CD8$^+$ T cells that are functionally and in many cases molecularly distinct. Currently, there are no unique surface markers that allow for easy discrimination between these CD8$^+$ phenotypes. Thus, accurate identification requires a more in depth analysis that includes examination of cell surface phenotype, functional phenotype, and expression of intracellular markers. Here, we have summarized the current knowledge of CD8$^+$ phenotypes in cancer (**Box 1**). We recommend avoiding the use of broad terms like "pro-tumor" or "antitumor" CD8$^+$ T cells without providing information on their functional state. We further propose that the term CTL should only be employed when corresponding cytotoxic functions have been experimentally demonstrated and that the term "dysfunctional" rather than "anergic" or "exhausted" be used to describe CD8$^+$ T that exhibit functional deficits in cancer. Importantly, we caution against ascribing CD8$^+$ T cells as dysfunctional based on the expression of co-inhibitory receptors alone. Future studies incorporating T cell analyses should include appropriate markers and functional assays to better define the phenotypes of T cells in peripheral blood, peripheral lymphoid tissues, and tumor biopsy samples.

Financial and Competing Interests Disclosure

MB is currently working as a scientific director of Institut Mérieux, a private company implementing *in vitro* diagnostics and immunotherapeutic approaches in oncology and infectious diseases. CM is Chief Scientific Officer of ISA Pharmaceuticals, a private biotech company developing synthetic therapeutic vaccines against cancer.

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Box 1. Distinguishing Features of CD8$^+$ T cell phenotypes

Terminal effector T cells- Surface features are expression of KLRG-1 and loss of CD62L, CCR7, CD27, and CD28. Important molecular features include high expression of the transcription factors *eomes* and *Id2*. Important cellular features are low IL-2 production, strong TNFα, IFNγ, and cytotoxic function but poor ability to self-renew.

Dysfunctional T cells- Surface features are expression of multiple co-inhibitory receptors such as CTLA-4, PD-1, Tim-3, and Lag-3. Important cellular features are defects in various effector functions: proliferative response to antigen stimulation, cytotoxicity, and secretion of pro-inflammatory cytokines (IL-2, TNFα, and IFNγ). It is important to note that dysfunctional T cells may not exhibit defects in all effector functions and thus dysfunctional phenotypes exist across a spectrum of weak to severe dysfunction.

Senescent T cells- Surface features are expression of KLRG-1 and CD57 and lack of CD27 and CD28. Important distinguishing cellular features are short telomeres, irreversible cell-cycle arrest, activation of DNA damage response (DDR) genes such as ATM and γH2AX, the presence of senescence-associated secretory phenotype (IL-6 and IL-8), and the presence of senescence-associated heterochromatin foci (SAHF). SAHF are foci

of facultative or repressed heterochromatin associated with gene-silencing.

Stem-like T cells- Surface features are expression of CCR7 and expression of CD62L, CD45RA, CD27, and CD28. Important molecular features are expression of the transcription factors *Id2* and *Tcf7*. Important cellular features are potent cytotoxicity *in vivo* and ability to self-renew.

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