

Review

Immunological Functions of the Omentum

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The omentum is a visceral adipose tissue with unique immune functions. Although it is primarily an adipose tissue, the omentum also contains lymphoid aggregates, called milky spots (MSs), that contribute to peritoneal immunity by collecting antigens, particulates, and pathogens from the peritoneal cavity and, depending on the stimuli, promoting a variety of immune responses, including inflammation, tolerance, or even fibrosis. Reciprocal interactions between cells in the MS and adipocytes regulate their immune and metabolic functions. Importantly, the omentum collects metastasizing tumor cells and supports tumor growth by immunological and metabolic mechanisms. Here we summarize our current knowledge about the development, organization, and function of the omentum in peritoneal immunity.

Development of the Omentum and Milky Spots

The **omentum** (see [Glossary](#)) is a visceral adipose tissue (VAT) derived from **mesothelial cells** [1], connected to the spleen, stomach, pancreas, and colon [2,3]. Although well known as a visceral fat depot, the role of the omentum in peritoneal immunity was not recognized until the early 1900s, when a British surgeon referred to it as ‘the policeman of the abdomen’ due to its ability to attenuate peritonitis and promote surgical wound healing [4]. In fact, the omentum was noted to move about the peritoneal cavity and occlude sites of inflammation, such as ruptured ovaries, inflamed appendices, ulcerated intestines, or wounds due to trauma or surgery [4]. Consistent with this observation, the omentum has remarkable angiogenic [5], fibrotic [6], stem cell [7,8], and immune [9] activities, which together promote vascularization, accelerate wound healing, and limit infection. However, these same activities are also likely involved in pathological responses, such as the rapid growth of omental tumor metastases [10].

In mice, the omentum is a relatively small strip of fat found anterior and slightly ventral to the stomach [11]. However, in humans the omentum is dramatically larger – reaching an area of 1500 cm² and resembling an apron that hangs in front of the abdominal organs [12]. The omentum in mice is a relatively small fat depot compared to those around the gonads and mesentery, whereas in humans, it is a major depot of abdominal fat. Nevertheless, the omenta of both mice and humans contain ‘milky spots’ (MSs), which are aggregates of leukocytes that in many ways resemble the follicles of secondary lymphoid tissues. In this review, we will concentrate on the immune functions of the omentum and the MSs and how the activities of these tissues regulate peritoneal immunity.

The MSs of the omentum were first described in 1874 in rabbits by the French anatomist, Ranvier, who gave them their name because of their whitish appearance amidst the yellow fat [13]. MSs are organized aggregates of leukocytes embedded between adipocytes just beneath the mesothelial cell layer that covers the omentum (Figure 1). Similar aggregates, known as **fat-associated lymphoid clusters (FALCs)**, are found in other fat depots, including the pericardial and mediastinal fat in the pleural cavity [14–16] as well as the mesenteric fat in the

Trends

VAT-associated Tregs are a transcriptionally and functionally unique population of Tregs that regulate immune responses and metabolic processes in adipose tissues, including the omentum.

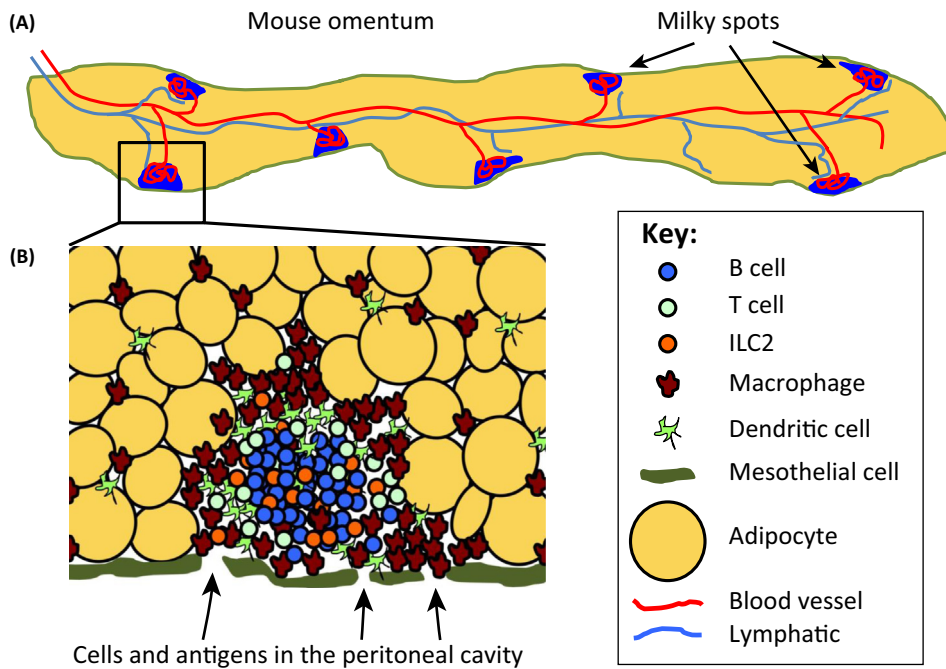
ILC2 cells are found in adipose tissues like the omentum, where they regulate local immune responses and adipocyte metabolism.

The omentum is a well characterized site of ovarian cancer metastasis, due to its ability to collect tumor cells from the peritoneal cavity and to support tumor cell metabolism and growth.

Despite the immune functions of the omentum, it appears unable to promote adaptive immune response to tumors that implant in the milky spots.

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Trends in Immunology

Figure 1. Structure of Milky Spots in the Omentum. (A) Schematic of whole omentum in mice. The omentum is a thin strip of fat (yellow) that is covered by a layer of mesothelial cells (green). **Milky spots (MSs)** (blue) are located just beneath the mesothelial layer embedded between adipocytes. The omentum is well vascularized with an extensive network of capillaries (not shown), which connect to a large central blood vessel (red), running between the adipocytes. Blood vessels also connect to the MSs and form a glomerulus-like knot of blood vessels in the lymphoid clusters. A large central lymphatic vessel (light blue) runs down the center of the omentum and branches from this vessel lead to MSs as well as to areas of the omentum that lack MSs. The human omentum is much larger and resembles an apron hanging in front of the abdomen, but also contains MSs. (B) Structure of MS. MSs are loose collections of leukocytes embedded between adipocytes (yellow) just beneath the mesothelial layer (green). B cells (blue) form a central cluster, whereas macrophages (brown) and dendritic cells (light green) tend to accumulate around the outside of the MS and are also found individually throughout the omentum. T cells (green circles) and ILCs (orange) can be intermixed with the B cells or may cluster around blood vessels (not shown). Cells and antigens are passively collected from the peritoneal cavity through fenestrations in the mesothelial layer by fluid flow or may be actively carried by phagocytic cells like macrophages. Cells can also enter the MSs from the blood through HEVs (not shown).

peritoneal cavity [14,17]. Although the leukocyte clusters in the omentum and the splenoportal adipose tissue are the only ones known as MSs [18,19], the MSs and FALCs are structurally similar, contain similar populations of leukocytes and likely perform similar immune functions. Interestingly, the frequency of MSs and FALCs are different depending on the tissue, with the omentum containing the highest frequency of clusters per gram of tissue, followed by the pericardial, mediastinal, and mesenteric adipose tissues [14]. Perigonadal fat and subcutaneous fat have few, if any, leukocyte clusters that resemble MSs or FALCs.

MSs in the omentum form during fetal development in both humans [20] and mice [14]. Although the development of most secondary lymphoid organs requires lymphotoxin and a subset of innate lymphoid cells (ILCs), known as lymphoid tissue-inducer (LTi) cells, for their development [21], MSs and FALCs do not require these interactions [9,14]. In fact, MSs develop independently of the transcription factors, ROR γ t and Id2 [9], which are essential for the differentiation of LTi cells and all ILCs, respectively [22]. Interestingly, mesenteric FALCs develop in normal numbers in *Rag2*^{-/-} mice and *Rorc*^{-/-} mice, but fail to develop in *Rag2*^{-/-} *Il2rg*^{-/-} mice [14], demonstrating that some type of innate or adaptive lymphocyte is important for their development. Thus, it is possible that ILC2 cells, which are relatively abundant in

Glossary

Fat-associated lymphoid clusters (FALCs): FALCs are similar to MSs in that they are clusters of leukocytes embedded in adipose tissue, primarily in mesenteric and pleural fat. However, FALCs are partially dependent on microbiota for their formation and are smaller and less frequent than the MSs of the omentum. Their function may be similar.

Mesothelial cells: a thin layer of cells that covers the omentum and other visceral and pleural organs. The surface of mesothelial cells is slippery to reduce friction between organs. Mesothelial cells are a potent source of TGF β in the omentum.

Milky spots (MSs): clusters of leukocytes embedded in adipose tissue, primarily in the omentum and the splenic-portal fat. They function similar to lymph nodes, in that they collect and respond to local antigens. However, the cellular composition of MSs more closely resembles the cells in the peritoneal cavity than cells in conventional secondary lymphoid organs like lymph nodes and spleen.

Omentum: a specialized adipose tissue in the peritoneal cavity that is connected by a mesothelial layer to the spleen, stomach, transverse colon, and pancreas. In mice it appears as a thin strip of fat, whereas in humans the omentum is an apron-like sheet that hangs in front of the visceral organs.

Parabiosis: a surgical technique in which two mice, usually expressing distinct markers, are surgically joined by the skin, side-by-side, so that they share a circulation. This technique allows cells in the blood to circulate between the joined animals, and is used to analyze whether cells are circulating or resident (based on the presence of cells with both markers, or the only host's markers, respectively).

SLP mice: spleen, lymph node, and Peyer's patch-deficient mice are generated by surgically removing the spleen from lymphotoxin-deficient mice (which lack lymph nodes and Peyer's patches) and irradiating splenectomized *Lta*^{-/-} mice and reconstituting them with WT BM. The omentum and MSs remain in these mice, allowing investigators to isolate their activity from other lymphoid organs.

adipose tissues [23,24], functionally replace LTi cells during the development of MSs and FALCs.

Exposure to microbiota or microbial products enhances the postnatal maturation of MSs and increases the number of observable FALCs in the mesenteric adipose tissue [14]. Conversely, the number of FALCs in the mesenteric fat is reduced by about half in germ-free mice. Moreover, the peritoneal administration of zymosan, a TLR-2-stimulating glucan, promotes the formation of additional FALCs in a process that is dependent on both TNF and CD1d-restricted NKT cells [14]. However, it is not clear whether this increase results from an expansion of previously existing, but very small clusters, or the *de novo* development of entirely new clusters. Regardless, these data demonstrate that both the primary development and postnatal enhancement of MSs and FALCs uses mechanisms distinct from those used by conventional lymphoid organs and suggest that MSs and FALCs should be categorized somewhere between true secondary lymphoid organs and tertiary lymphoid tissues.

Structure of Omental Milky Spots

The leukocyte clusters in MSs are distinctly different from conventional secondary lymphoid tissues. For example, although the leukocytes in MSs are supported by a reticular network of fibroblastic stromal cells that can be observed using the ERTR-7 antibody [9], they lack identifiable follicular dendritic cells (FDCs) [9,25]. The B cell-attracting chemokine, CXCL13, which is associated with FDC networks in conventional lymphoid organs [26], is also strongly expressed in the MS [27]. However, CXCL13 expression in the MS is observed outside the B cell clusters in an area with abundant FDCM1⁺CD11b⁺ cells [9,27]. Given that macrophages are a potent source of CXCL13 in the peritoneal cavity and omentum [27], it is likely that these CD11b⁺CXCL13⁺ cells are macrophages.

T cells in MSs seem to be clustered around blood vessels [9], perhaps high endothelial venules (HEVs). However, T cells are also found in the B cell area, consistent with the placement of T follicular helper (Tfh) cells, although *bona fide* Tfh cells have not yet been identified in MSs or FALCs. Despite the presence of both CD4⁺ and CD8⁺ T cells [25], it is difficult to discern a well-defined T cell zone. Moreover, it is not clear whether cells with markers of fibroblastic reticular cells (FRCs) are present in MSs or whether they are restricted to a particular region. Thus, although MSs do have a compartmentalized structure, it is strikingly different from that seen in conventional lymphoid organs.

The omentum as a whole is highly vascularized and MSs in particular are formed around a glomerulus-like knot of blood vessels [25,28] (Figure 1). Some of these vessels express markers of HEVs [9,25], including peripheral lymph node addressin (PNAd) and mucosal addressin cell adhesion molecule 1 (MAdCAM-1). MAdCAM is typically expressed by HEVs in mucosal lymphoid tissues, such as Peyer's patches and mesenteric lymph nodes [29], but not peripheral lymph nodes, and helps to recruit mucosal-homing lymphocytes from the blood [9,30]. Not surprisingly, the mucosal-associated integrin, $\alpha 4\beta 7$, which is the ligand for MAdCAM, is involved in migration from the blood to the omentum [30,31].

The lymphatic architecture of the omentum and MSs is also distinct from that in conventional secondary lymphoid organs. For example, lymph nodes collect antigens via afferent lymphatic vessels that deliver cells and antigens to the subcapsular sinus, whereas Peyer's patches and other mucosal lymphoid tissues acquire antigens from mucosal surfaces via specialized M cells in the mucosal epithelium. By contrast, MSs lack afferent lymphatics and collect cells and antigens from the peritoneal cavity through fenestrations in the mesothelial layer [9,28,31] (Figure 1). Efferent lymphatic vessels, on the other hand, originate around the MS or as a network of endothelial channels between adipocytes [3,25,28] and drain toward downstream

Visceral adipose tissue (VAT)-associated Tregs: a subset of FoxP3⁺ Tregs that reside in adipose tissue, including the omentum. These cells depend on the transcription factor PPAR γ , which is normally associated with adipocyte differentiation. They are found in perigonadal fat, which lacks MSs or FALCs.

lymph nodes. In humans, the lymphatic drainage of the omentum empties toward the subpyloric or splenic lymph nodes [32], whereas in mice, the lymphatic drainage empties to the mediastinal or perithymic lymph nodes.

Fluid is continuously drained from the peritoneal cavity, in large part, through the lymphatics of the omentum, carrying with it any free-floating cells, particulates or antigens. As a result, MSs function as filters for the peritoneal fluid, making them ideally situated to generate immune responses to any antigens or pathogens in the peritoneal cavity. Fluid flow through the omentum can be increased, for example by peritoneal dialysis, which leads to a dramatic enlargement of the MSs and ultimately promotes omental fibrosis [33,34]. Conversely, tumor cells entrapped by MSs form omental metastases that eventually plug the lymphatic drainage and allow the accumulation of ascites fluid in the peritoneal cavity [35].

Cellular Composition of the Omentum and MSs

The leukocyte populations in MSs and other FALCs are also quite distinct from those in conventional lymphoid tissues [11,27]. B cells make up the majority of lymphocytes in MSs [9]. However, IgM^{hi}IgD^{lo} B1 cells outnumber IgM^{lo}IgD^{hi} follicular B2 cells in MSs, whereas the opposite is true in conventional lymphoid organs [11,20,27,36]. B1 cells are generated by fetal-derived hematopoietic progenitors, some of which contribute to local B1 lymphopoiesis in the omenta of both mice and humans [37,38]. In adults, self-renewing B1 B cells are maintained in the omentum and peritoneal cavity [27,37], a process that is dependent on the chemokine CXCL13 [9,27]. Interestingly, **parabiosis** studies show that the majority of B1 cells are permanent residents of the omentum and peritoneal cavity [27], whereas the B2 cells in the omentum recirculate between the omentum and other lymphoid tissues.

The omentum also harbors recirculating CD4⁺ and CD8⁺ T cells, although at lower frequencies than in conventional lymphoid organs [25]. By contrast, MSs and other FALCs contain higher frequencies of CD1d-restricted NKT cells than conventional lymphoid organs [11]. These NKT cells are depleted (as a fraction of T cells or of total CD45⁺ cells) from the omenta of obese humans and those with cancer [39], a finding consistent with observations in obese mice [40]. Interestingly, fat-associated NKT cells are enriched for cells that produce IL-10 [41], suggesting an anti-inflammatory function for these cells. Consistent with this idea, most studies suggest that mice lacking NKT cells gain more weight on a high-fat diet, have more inflammatory macrophages in adipose tissue, and become insulin resistant [40,42]. Although these metabolic studies did not test the role of NKT cells specifically in the omentum, the prevalence of these cells in this tissue undoubtedly influences a variety of local immune reactions, such as the expansion of FALCs in response to inflammatory stimuli [14].

The omentum also supports a unique population of **VAT-associated CD4⁺ regulatory T cells (Tregs)** [43] that express the chemokine receptors, CCR1 and CCR2, produce high levels of IL-10, and express proteins like CD36, which is involved in fatty acid metabolism [43,44]. The phenotype of VAT-associated Tregs is conferred by the transcription factors, PPAR γ , BATF, and IRF4 as well as by IL-33 signaling through ST2 [43,45]. Although VAT-associated Tregs are mostly studied in large fat depots like epididymal fat, which lack MSs, they are also found in the omentum [43], where they likely regulate local immune responses. Interestingly, obesity is associated with the loss of VAT-associated Tregs in epididymal fat and a corresponding increase in inflammatory cells and cytokines [43,44]. In fact, the depletion of VAT-associated Tregs by blockade of the IL-33 receptor, ST2, increases adipose tissue insulin sensitivity [46], suggesting a direct role of Tregs in regulating metabolism. Moreover, in obese mice, the VAT-associated Tregs lose the gene expression signature typical of lean individuals and are less capable of suppressing inflammation [43]. Although these data were obtained in fat depots like the epididymal fat, which does not contain MSs, VAT-associated

Tregs are found in the omentum and are likely important regulators of metabolism and inflammation in this tissue as well.

Innate lymphoid cells (ILCs), particularly ILC2 cells, are also found in adipose tissues, including the omentum [15,24]. Like VAT-associated Tregs, ILC2 cells express ST2 and respond to local IL-33 [15]. Interestingly, the IL-33-induced expression of IL-5 by ILC2 cells in the FALCs of the pericardium promotes the differentiation of local B1 B cells into IgM-secreting cells [15]. Given that ILC2 cells are also present in the omentum, a similar process likely occurs in this location [47]. ILC2 cells also help regulate metabolic functions. For example, decreases in ILC2 cells in adipose tissue are associated with obesity in both humans and mice [24]. Similar to its role in VAT-associated Tregs, IL-33 is important for the maintenance of ILC2 cells in adipose tissue and in limiting adiposity in mice by increasing caloric expenditure [24]. IL-25 is also implicated in the homeostasis and activation of ILC2 cells in adipose tissue [48]. The administration of IL-25 to obese mice increases ILC2 cells in VAT and also promotes weight loss and improves glucose tolerance, as does the adoptive transfer of ILC2 cells. Conversely, the depletion of ILC2 cells in obese *Rag1*^{-/-} mice promotes weight gain and glucose intolerance [48]. Although the metabolism-regulating activities of ILC2 cells are not limited to the omentum, the omentum is the major depot of abdominal fat in humans and is particularly associated with metabolic disease [49].

Numerous macrophages are found in the omentum under steady-state conditions, although dendritic cells (DCs) are also present in MSs [11,27]. In particular, the omentum and peritoneal cavity hosts a distinctive subset of resident macrophages that is dependent on the transcription factor GATA6 [50]. Interestingly, the GATA6⁺ macrophages express high levels of retinaldehyde dehydrogenase-2 (RALDH2) [50,51], an enzyme that generates retinoic acid (RA), which is a key factor in isotype-switching to IgA [52,53]. The omentum also maintains macrophage precursors [54], and supports macrophage proliferation [55] via the production of macrophage colony-stimulating factor (M-CSF) by MS stromal cells [56]. Like B1 cells, macrophages are noncirculating residents of the omentum and peritoneal cavity [27]. A subset of peritoneal macrophages is also derived from CCR2-expressing monocyte precursors [57]. The differentiation of these monocyte-derived macrophages is dependent on the transcription factor, IRF4, and requires commensal microbiota [57], again suggesting a connection between the gut and the peritoneal cavity and omentum.

Given the unique populations of Tregs, ILC2 cells, NKT cells, and macrophages in the omentum and MSs, it is easy to imagine that these cells influence local immune responses, perhaps by dampening inflammatory responses. Other cells, such as B1 cells, seem poised to respond to bacterial antigens and to promote mucosal immunity in the gut. B1 cells also make IL-10 [58] and may contribute to the anti-inflammatory and perhaps tolerogenic environment of the omentum. Consistent with these ideas, the transfer of omental leukocytes from healthy mice to mice with DSS-induced colitis reduces inflammation, promotes healing of the damaged colon, restores body weight and reduces colitis-associated mortality [59].

Immune Responses in the Omentum

Consistent with its ability to collect antigens and cells from the peritoneal cavity, the MS of the omentum support both innate and adaptive immune responses to peritoneal antigens. For example, inflammation in the peritoneal cavity promotes the rapid migration of macrophages to the omentum – a process originally known as the macrophage disappearance reaction [60]. This process can be driven by sterile irritants, including LPS [61], zymosan [14], or thioglycollate [50], as well as inert particles, such as polydextran or silicone beads, which are carried to the omentum by macrophages. All of these stimuli promote the expansion of MSs and the

production of factors like vascular endothelial growth factor (VEGF) and chemokines like CXCL12 [62–64].

Similar events occur following peritoneal exposure to bacteria. For example, peritoneal administration of attenuated *Streptococcus pyogenes* triggers the activation of macrophages that engulf the bacteria, home to the omentum and increase both the cellularity and quantity of MSs [65]. Importantly, increases in the cellularity of MSs are not only driven by the influx of peritoneal cells, but are also due to the recruitment of cells from the blood. In fact, large numbers of circulating neutrophils migrate into the omentum during acute inflammation and sepsis [36]. This process occurs by trafficking across HEVs in the MSs and requires PNA^d as well as E-selectin, L-selectin, and Mac-1 [66].

The inflammation-driven influx of cells from the peritoneal cavity also promotes adaptive immune responses. For example, infection or inflammation-driven production of IL-33 triggers the production of IL-5 by ILC2 cells, which in turn promotes the differentiation of local B1 cells in the FALCs and MSs [15]. Peritoneal administration of LPS also promotes the migration of peritoneal B1 cells to the MS [50,51,61], where they differentiate into IgM-secreting and IgA-secreting cells, some of which colonize the intestine [67,68], possibly by CXCR4-dependent mechanisms [69]. The omentum also supports the formation and local maintenance of IgM⁺ memory B cells and CD11c⁺ IgM plasmablasts in response to peritoneal infection [47]. Importantly, LPS-mediated peritoneal inflammation triggers the rapid accumulation of GATA6⁺ macrophages in the omentum, which produce RA [50,51], a key factor in isotype switching to IgA [52,53]. RA also imprints responding B and T cells with gut-homing receptors, such as α 4 β 7 and CCR9 [70,71]. Surprisingly however, GATA6-dependent macrophages do not imprint α 4 β 7 and CCR9 expression on B cells responding to antigens in the peritoneal cavity and omentum [50].

Despite an obvious focus on B1 responses in the omentum, MSs also support B cell germinal center responses to classic T-dependent antigens, such as haptenated OVA, when administered in the peritoneal cavity [9]. However, B cells responding to T-dependent antigens in MSs are poorly selected for high-affinity variants [9], consistent with the lack of FDCs in MSs. Nevertheless, T-dependent B cell responses in MSs lead to high titers of antigen-specific serum IgG [9]. Importantly, these can occur in mice lacking conventional secondary lymphoid organs (spleen, lymph node, and Peyer's patch-deficient mice – **SLP mice**) [47]. Thus, although some might argue that the primary purpose of the MS is to support the rapid differentiation of B1 cells into IgM- and IgA-secreting cells, conventional, T-dependent B cell responses also occur in these sites.

MSs also support primary responses of conventional T cells. For instance, the initial activation and first divisions of OVA-specific CD4⁺ and CD8⁺ T cells occur in the omentum of SLP mice following peritoneal immunization with OVA [9]. Similarly, H-Y-specific CD8⁺ T cells are initially activated and proliferate in the omentum before appearing in the peritoneal cavity [31]. Moreover, CD11c⁺MHCII^{hi} DCs from the omentum are potent antigen-presenting cells with the ability to cross-present soluble antigens [31]. About 70% of these DCs highly express CD11b, whereas about 30% express CD103 – a ratio consistent with the composition of migratory DCs in a variety of nonlymphoid organs. Importantly, T cells primed *in vitro* by DCs from the omentum consistently express α 4 β 7, whereas T cells primed by splenic DCs do not [31], suggesting that omental DCs have mechanisms, such as RALDH2 expression, for promoting the differentiation of mucosal homing T cells. Although these DCs are distinct from GATA6⁺ macrophages, which also express RALDH2 [50], both cell types may promote the differentiation of mucosal homing T cells or inducible Tregs through the production of RA [70,72,73].

In addition to priming naïve T cells, the omentum also collects recirculating memory T cells that are generated at distal sites. For example, mice orally infected with *Heligmosomoides polygyrus*, a helminth restricted to the gastrointestinal tract [74], accumulate helminth-specific Th2 cells in the peritoneal cavity and omentum [9]. Similarly, mice nasally infected with influenza virus accumulate influenza-specific memory CD4⁺ and CD8⁺ T cells in the peritoneal cavity and omentum [9]. Both of these responses are mucosal, suggesting that mucosal-homing cells may preferentially home to the omentum. However, a direct comparison with antigen-specific T cells generated at systemic sites has not been performed.

The omentum and MSs clearly have the cell types and immune mechanisms to promote anti-inflammatory or tolerogenic responses under steady-state conditions, perhaps as a way to maintain adipocyte homeostasis. The activities of the omentum and MSs are also strongly linked to mucosal immunity and IgA production in the gut, and may use these same mechanisms and cell types to suppress inflammatory responses to gut antigens and maintain intestinal homeostasis. However, there is no evidence that gut antigens or intestinal DCs are directly sampled by the MS unless the intestine is completely breached – a highly inflammatory and nonhomeostatic event! If this is the case, then how do cells in the MS respond to antigens from the gut during homeostasis (see Outstanding Questions)?

Peritoneal Tumor Metastasis in the Omentum

Primary tumors of the omentum are uncommon. However, the omentum is the most common site of peritoneal metastasis for some tumors, including gastrointestinal and ovarian carcinoma [28,75,76]. In particular, ovarian cancer disseminates early and robustly to the omentum, where it is associated with poor prognosis and aggressive growth [10,77,78]. Despite the fact that immune responses can be initiated in the MSs of the omentum, a protective immune response against tumors seems to not occur and metastatic tumor cells grow progressively [78].

Consistent with studies of inert antigens in the peritoneal cavity, live tumor cells injected into the peritoneal cavity are trapped in the MSs [9,28] – a finding that is consistent for multiple tumor cell lines, including B16 melanoma, ID8 ovarian carcinoma, EG7 lymphoma, MC38 colon carcinoma, gastric carcinoma, and EMT6 lung carcinoma [28,79]. In each of these cases, tumor cells initially colonize the MSs before being observed in non-MS areas of the omentum. In some cases, this phenomenon is attributed to the selective recruitment of CCR4-expressing tumor cells to CCL22-expressing macrophages in the MS [80]. However, the accumulation of tumor cells in the MS is not necessarily dependent on chemotaxis, as pertussis toxin-treated EL4 cells administered to the peritoneal cavity accumulate in the MS just as rapidly as untreated cells [9]. Thus, although chemokine-dependent migration of tumor cells to the omentum and MSs undoubtedly occurs for some tumor cells, they can also accumulate passively due to fluid flow from the peritoneal cavity through the MSs and the omentum.

Although the omentum efficiently collects tumor cells from the peritoneal cavity, ovarian tumor cells circulating in the blood also preferentially metastasize to the omentum. In fact, a recent study shows that parabiotic joining of a tumor-bearing mouse with a non-tumor-bearing mouse leads to ovarian tumor metastasis to the partner omentum [81]. Given that parabiotic mice have a joint circulation, but independent lymphatic systems, this study shows a metastatic preference for the omentum, even when tumor cells are freely circulating throughout the body [81]. In part, this preference can be attributed to ErbB2, also known as HER2/neu, a member of the epidermal growth factor receptor family [81], which is expressed by tumor cells, and its ligand, neuregulin 1 (NRG1), which is expressed by unknown cell types surrounding the omental vasculature. A similar phenomenon may occur in humans, in which an increase in ErbB2 expression in ovarian carcinoma cells correlates with advanced staging of the tumors [81]. Ovarian cancer cells also stimulate omental fibroblast proliferation via transforming growth

factor (TGF)- β 1, which facilitates tumor cell implantation and subsequent dissemination [82]. Tumor cell implantation in the MS also promotes local angiogenesis due to the production of VEGF-C [79] and VEGF-A [28] by mesothelial cells. An additional explanation for the preferential tumor growth in omentum in ovarian cancer is attributed to the adipocytes themselves. Adipocytes express fatty-acid binding proteins (FABP) [83], including FABP4, which promotes lipid transfer from adipocytes to tumor cells and facilitates β -oxidation metabolism in tumor cells, thereby enhancing their proliferation and invasiveness [84]. Thus, the omentum is an ideal environment for tumor cell metastasis and subsequent growth.

How does the immune activity of leukocytes in the MS impact tumor growth? The initial colonization of tumor cells triggers an increase in MS size and number, mainly by macrophage recruitment from the peritoneal cavity [65]. Despite this apparent activation, the tumor cells continue to grow [76,78], suggesting a lack of immune recognition or perhaps a potent immune-suppressive effect. Nevertheless, there are indications that ovarian cancer can be recognized by the immune system [85]. For example, the presence of tumor infiltrating lymphocytes (TILs), particularly CD8⁺ T cells, in both primary tumors (ovary) and metastatic tumors (omentum), positively correlates with overall survival [86,87], whereas the absence of TILs correlates with treatment failure. Similarly, patients whose tumors have gene expression signatures of CD8⁺ T cells and antigen presentation pathways have a good prognosis [88,89]. Conversely, the presence of Tregs in both malignant ascites and tumor mass is associated with poor outcomes [90].

The VEGF-driven accumulation of CD33⁺ myeloid-derived suppressor cells (MDSCs), particularly in the omentum, also correlates with a failure to accumulate CD8⁺ TILs, the suppression of T cell function and a poor prognosis in ovarian cancer patients [91]. Similarly, CD33⁺ MDSCs that accumulate in peritoneal ascites fluid of ovarian cancer patients express nitric oxide synthase-2 (NOS2) and produce NO [92], which promotes the differentiation of Th17 cells and impairs the function of Th1 and CD8⁺ T cells. Although Th17 responses can in some cases promote antitumor immunity [93], chronic IL-17-driven inflammation is also associated with tumorigenesis [94]. Thus, a feed-forward loop between Th17 cells and MDSCs in the peritoneal cavity and omentum is likely a driver of ovarian cancer metastasis and progression.

Given our understanding of the immune activities of the omentum and MSs, it seems reasonable to devise immune strategies to target these sites and benefit local antitumor immunity. For example, phagocytic cells in the omentum can be targeted with antigen-loaded, oligomannose-coated liposomes, which promote tumor-antigen-specific CD8⁺ T cell responses and impair tumor growth [95]. Similarly, peritoneal vaccination with lethally irradiated tumor cells leads to a local NK-mediated immune response in the MS that impairs subsequent tumor growth [96]. Consistent with the immune suppressive properties of the omentum, TILs from human ovarian tumor fragments grafted in the omentum of immunodeficient mice are anergic [97]. However, the administration of IL-12 loaded liposomes promotes local T cell reactivation, impairs tumor growth, and prolongs survival [97]. In addition to immunological interventions, physicians now use intraperitoneal chemotherapy to increase overall survival in ovarian cancer patients [98], although the role of the omentum or the MS is unclear at this time. Together, these studies suggest that therapies that target antigens or drugs to the omentum may be important for controlling peritoneal tumors. However, surgeons often resect most or all of the omentum in the context of ovarian cancer to eliminate as much metastatic disease as possible [77,78].

Interestingly, omentectomy is also used in combination with gastric bypass surgery to promote weight loss and reduce symptoms of metabolic syndrome [99–101]. Although some studies suggest that omentectomy lowers inflammatory markers in skeletal muscle [99], and reduces C-reactive protein in serum [102], more recent trials find that omentectomy provides no

additional benefit over gastric bypass alone with regards to metabolic parameters [100,101]. These data may suggest a differential role of the omentum in regulating inflammatory and metabolic processes, perhaps due to its immune functions. Unfortunately, we have no information on peritoneal immune responses following omentectomy in patients with obesity or ovarian cancer.

Concluding Remarks

We now understand that the immune activity of the omentum is highly specialized and that its unusual leukocyte composition has likely evolved to maintain adipocyte homeostasis, protect the unique environment of the peritoneal cavity and promote the differentiation of mucosal-homing cells that recognize gut antigens. Importantly, this model suggests that perturbations of omental functions that may occur in the context of obesity, tumor metastasis, peritoneal dialysis or most extremely, omentectomy, may also have unpredictable effects on immune regulation in the gut and peritoneal cavity, the progression of metabolic disease, tumor progression, or even systemic inflammation. Thus, the omentum is an immunologically important, albeit poorly understood and often overlooked, regulator of regional immune responses.

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References

- Chau, Y.Y. *et al.* (2014) Visceral and subcutaneous fat have different origins and evidence supports a mesothelial source. *Nat. Cell Biol.* 16, 367–375
- Williams, R. and White, H. (1986) The greater omentum: its applicability to cancer surgery and cancer therapy. *Curr. Probl. Surg.* 23, 789–865
- Wilkosz, S. *et al.* (2005) A comparative study of the structure of human and murine greater omentum. *Anat. Embryol.* 209, 251–261
- Morrison, R. (1906) On the functional aspects of the greater omentum. *Br. Med. J.* 1, 76–78
- García-Gomez, I. *et al.* (2005) Angiogenic capacity of human omental stem cells. *Neuro. Res.* 27, 807–811
- Divoux, A. *et al.* (2010) Fibrosis in human adipose tissue: composition, distribution, and link with lipid metabolism and fat mass loss. *Diabetes* 59, 2817–2825
- Shah, S. *et al.* (2012) Cellular basis of tissue regeneration by omentum. *PLoS One* 7, e38368
- Russo, V. *et al.* (2014) Comparison of human adipose-derived stem cells isolated from subcutaneous, omental, and intrathoracic adipose tissue depots for regenerative applications. *Stem Cells Transl. Med.* 3, 206–217
- Rangel-Moreno, J. *et al.* (2009) Omental milky spots develop in the absence of lymphoid tissue-inducer cells and support B and T cell responses to peritoneal antigens. *Immunity* 30, 731–743
- Koppe, M.J. *et al.* (2014) Recent insights into the pathophysiology of omental metastases. *J. Surg. Oncol.* 110, 670–675
- Cohen, C.A. *et al.* (2013) Intra-abdominal fat depots represent distinct immunomodulatory microenvironments: a murine model. *PLoS One* 8, e66477
- Platel, C. *et al.* (2000) The omentum. *World J. Gastroenterol.* 6, 169–176
- Ranvier, I. (1874) Du développement et de l'accroissement des vaisseaux sanguins. *Arch. Physiol. Norm. Path.* 6, 429–449 (in French)
- Benezech, C. *et al.* (2015) Inflammation-induced formation of fat-associated lymphoid clusters. *Nat. Immunol.* 16, 819–828
- Jackson-Jones, L.H. (2016) Fat-associated lymphoid clusters control local IgM secretion during pleural infection and lung inflammation. *Nat. Commun.* 7, 12651
- Elewa, Y.H. *et al.* (2014) Characterization of mouse mediastinal fat-associated lymphoid clusters. *Cell Tissue Res.* 357, 731–741
- Moro, K. *et al.* (2010) Innate production of T_H2 cytokines by adipose tissue-associated c-Kit⁺Sca-1⁺ lymphoid cells. *Nature* 463, 540–544
- Clark, R. *et al.* (2013) Milky spots promote ovarian cancer metastatic colonization of peritoneal adipose in experimental models. *Am. J. Pathol.* 183, 576–591
- Takemori, N. *et al.* (1995) Light and electron microscope study of splenoportal milky spots in New Zealand black mice: comparison between splenoportal milky spots and aberrant spleens. *J. Anat.* 186, 287–299
- Krist, L.F. *et al.* (1997) Ontogeny of milky spots in the human greater omentum: an immunohistochemical study. *Anat. Rec.* 249, 399–404
- Cupedo, T. and Mebius, R.E. (2005) Cellular interactions in lymph node development. *J. Immunol.* 174, 21–25
- Spits, H. and Cupedo, T. (2012) Innate lymphoid cells: emerging insights in development, lineage relationships, and function. *Annu. Rev. Immunol.* 30, 647–675
- Lee, M.W. *et al.* (2015) Activated type 2 innate lymphoid cells regulate beige fat biogenesis. *Cell* 160, 74–87
- Brestoff, J.R. *et al.* (2015) Group 2 innate lymphoid cells promote beiging of white adipose tissue and limit obesity. *Nature* 519, 242–246
- Shimotsuma, M. *et al.* (1993) Morpho-physiological function and role of omental milky spots as omentum-associated lymphoid tissue (OALT) in the peritoneal cavity. *Lymphology* 26, 90–101
- Cyster, J.G. *et al.* (2000) Follicular stromal cells and lymphocyte homing to follicles. *Immunol. Rev.* 176, 181–193
- Ansel, K.M. *et al.* (2002) CXCL13 is required for B1 cell homing, natural antibody production, and body cavity immunity. *Immunity* 16, 67–76
- Gerber, S.A. *et al.* (2006) Preferential attachment of peritoneal tumor metastases to omental immune aggregates and possible role of a unique vascular microenvironment in metastatic survival and growth. *Am. J. Pathol.* 169, 1739–1752
- Briskin, M. *et al.* (1997) Human mucosal addressin cell adhesion molecule-1 is preferentially expressed in intestinal tract and associated lymphoid tissue. *Am. J. Pathol.* 151, 97–110

Outstanding Questions

Given the ability of the omentum to promote the differentiation of mucosal homing T cells and IgA-secreting B cells, how does the omentum sample mucosal antigens?

Given that mice are very often immunized in the peritoneal cavity, the MSs are likely the first site where immune cells encounter antigens – do they contribute to ‘systemic’ immune responses, and if so, how do they influence responses that are so often measured in the spleen?

Given the frequent metastasis of ovarian cancer to the omentum and the generally poor immunological outcomes, does the practice of omentectomy help antitumor responses by relieving immune suppression, or does it impair antitumor responses by removing MSs as sites of immune activation?

Does omentectomy affect immune homeostasis in the peritoneal cavity or gut?

30. Berberich, S. *et al.* (2008) Differential molecular and anatomical basis for B cell migration into the peritoneal cavity and omental milky spots. *J. Immunol.* 180, 2196–1203
31. Carlow, D.A. *et al.* (2009) Lymphocytes in the peritoneum home to the omentum and are activated by resident dendritic cells. *J. Immunol.* 183, 1155–1165
32. Liebermann-Meffert, D. (2000) The greater omentum. Anatomy, embryology, and surgical applications. *Surg. Clin. North Am.* 80, 275–293 xii
33. Beelen, R.H. *et al.* (2001) Rat models in peritoneal dialysis. *Nephrol. Dial. Transplant* 16, 672–674
34. Beelen, R.H. *et al.* (2005) Omental milky spots in peritoneal pathophysiology (spots before your eyes). *Perit. Dial. Int.* 25, 30–32
35. Sangisetty, S.L. and Miner, T.J. (2012) Malignant ascites: a review of prognostic factors, pathophysiology and therapeutic measures. *World J. Gastrointest. Surg.* 4, 87–95
36. Van Vugt, E. *et al.* (1996) Omental milky spots in the local immune response in the peritoneal cavity of rats. *Anat. Rec.* 244, 235–245
37. Solvason, N. *et al.* (1992) The fetal omentum in mice and humans. A site enriched for precursors of CD5 B cells early in development. *Ann. N Y Acad. Sci.* 651, 10–20
38. Solvason, N. and Kearney, J.F. (1992) The human fetal omentum: a site of B cell generation. *J. Exp. Med.* 175, 397–404
39. Lynch, L. *et al.* (2009) Invariant NKT cells and CD1d(+) cells amass in human omentum and are depleted in patients with cancer and obesity. *Eur. J. Immunol.* 39, 1893–1901
40. Lynch, L. *et al.* (2012) Adipose tissue invariant NKT cells protect against diet-induced obesity and metabolic disorder through regulatory cytokine production. *Immunity* 37, 574–587
41. Sag, D. *et al.* (2014) IL-10-producing NKT10 cells are a distinct regulatory invariant NKT cell subset. *J. Clin. Invest.* 124, 3725–3740
42. Ji, Y. *et al.* (2012) Activation of natural killer T cells promotes M2 Macrophage polarization in adipose tissue and improves systemic glucose tolerance via interleukin-4 (IL-4)/STAT6 protein signaling axis in obesity. *J. Biol. Chem.* 287, 13561–13571
43. Cipolletta, D. *et al.* (2015) Appearance and disappearance of the mRNA signature characteristic of Treg cells in visceral adipose tissue: age, diet, and PPAR γ effects. *Proc. Natl. Acad. Sci. U. S. A.* 112, 482–487
44. Feuerer, M. *et al.* (2009) Lean, but not obese, fat is enriched for a unique population of regulatory T cells that affect metabolic parameters. *Nat. Med.* 15, 930–939
45. Vasanthakumar, A. (2015) The transcriptional regulators IRF4, BATF and IL-33 orchestrate development and maintenance of adipose tissue-resident regulatory T cells. *Nat. Immunol.* 16, 276–285
46. Bapat, S.P. *et al.* (2015) Depletion of fat-resident Treg cells prevents age-associated insulin resistance. *Nature* 528, 137–141
47. Jones, D.D. *et al.* (2015) The omentum is a site of protective IgM production during intracellular bacterial infection. *Infect. Immun.* 83, 2139–2347
48. Hams, E. *et al.* (2013) Cutting edge: IL-25 elicits innate lymphoid type 2 and type II NKT cells that regulate obesity in mice. *J. Immunol.* 191, 5349–5353
49. Wajchenberg, B.L. (2002) Depot-specific hormonal characteristics of subcutaneous and visceral adipose tissue and their relation to the metabolic syndrome. *Horm. Metab. Res.* 34, 616–621
50. Okabe, Y. and Medzhitov, R. (2014) Tissue-specific signals control reversible program of localization and functional polarization of macrophages. *Cell* 157, 832–844
51. Maruya, M. *et al.* (2011) Vitamin A-dependent transcriptional activation of the nuclear factor of activated T cells c1 (NFATc1) is critical for the development and survival of B1 cells. *Proc. Natl. Acad. Sci. U. S. A.* 108, 722–727
52. Mora, J.R. and von Andrian, U.H. (2008) Differentiation and homing of IgA-secreting cells. *Mucosal. Immunol.* 1, 96–109
53. Mora, J.R. and von Andrian, U.H. (2009) Role of retinoic acid in the imprinting of gut-homing IgA-secreting cells. *Semin. Immunol.* 21, 28–35
54. Daems, W.T. and de Bakker, J.M. (1982) Do resident macrophages proliferate? *Immunobiology* 161, 204–211
55. Wijffels, J.F. *et al.* (1992) Milky spots in the mouse omentum may play an important role in the origin of peritoneal macrophages. *Res. Immunol.* 143, 401–409
56. Ratajczak, M.Z. *et al.* (1987) Omental lymphoid organ as a source of macrophage colony stimulating activity in peritoneal cavity. *Clin. Exp. Immunol.* 69, 198–203
57. Kim, K.W. *et al.* (2016) MHC II⁺ resident peritoneal and pleural macrophages rely on IRF4 for development from circulating monocytes. *J. Exp. Med.* 213, 1951–1959
58. O'Garra, A. and Howard, M. (1992) IL-10 production by CD5 B cells. *Ann. N Y Acad. Sci.* 651, 182–199
59. Jung, B.C. *et al.* (2013) Omentum cells promote healing of colonic tissues in dextran sulfate sodium (DSS) induced model of colitis in mice. *J. Lifestyle Med.* 3, 48–53
60. Barth, M.W. *et al.* (1995) Review of the macrophage disappearance reaction. *J. Leukoc. Biol.* 57, 361–367
61. Ha, S.A. *et al.* (2006) Regulation of B1 cell migration by signals through toll-like receptors. *J. Exp. Med.* 203, 2541–2550
62. Litbarg, N.O. *et al.* (2007) Activated omentum becomes rich in factors that promote healing and tissue regeneration. *Cell Tissue Res.* 328, 487–497
63. Saqib, N.U. *et al.* (2010) The omentum is a site of stromal cell-derived factor 1 α production and reservoir for CXCR4 chemokine receptor 4-positive cell recruitment. *Am. J. Surg.* 200, 276–282
64. Zhang, Q.X. *et al.* (1997) Vascular endothelial growth factor is the major angiogenic factor in omentum: mechanism of the omentum-mediated angiogenesis. *J. Surg. Res.* 67, 147–154
65. Shimotsu, M. *et al.* (1992) Activation of omental milky spots and milky spot macrophages by intraperitoneal administration of a streptococcal preparation, OK-432. *Cancer Res.* 52, 5400–5402
66. Buscher, K. *et al.* (2016) Protection from septic peritonitis by rapid neutrophil recruitment through omental high endothelial venules. *Nat. Commun.* 7, 10828
67. Fagarasan, S. *et al.* (2010) Adaptive immune regulation in the gut: T cell-dependent and T cell-independent IgA synthesis. *Annu. Rev. Immunol.* 28, 243–273
68. Suzuki, K. *et al.* (2010) Roles of B-1 and B-2 cells in innate and acquired IgA-mediated immunity. *Immunol. Rev.* 237, 180–190
69. Moon, H. *et al.* (2012) LPS-induced migration of peritoneal B-1 cells is associated with upregulation of CXCR4 and increased migratory sensitivity to CXCL12. *J. Korean Med. Sci.* 27, 27–35
70. Liu, Z.M. *et al.* (2015) The role of all-trans retinoic acid in the biology of Foxp3⁺ regulatory T cells. *Cell Mol. Immunol.* 12, 553–557
71. Bono, M.R. *et al.* (2016) Retinoic acid as a modulator of T cell immunity. *Nutrients* 8, 349
72. Mucida, D. *et al.* (2007) Reciprocal TH17 and regulatory T cell differentiation mediated by retinoic acid. *Science* 317, 256–260
73. Benson, M.J. *et al.* (2007) All-trans retinoic acid mediates enhanced T reg cell growth, differentiation, and gut homing in the face of high levels of co-stimulation. *J. Exp. Med.* 204, 1765–1774
74. Reynolds, L.A. *et al.* (2012) Immunity to the model intestinal helminth parasite *Heligmosomoides polygyrus*. *Semin. Immunopathol.* 34, 829–846
75. Hagiwara, A. *et al.* (1993) Milky spots as the implantation site for malignant cells in peritoneal dissemination in mice. *Cancer Res.* 53, 687–692
76. Krist, L.F. *et al.* (1998) Milky spots in the greater omentum are predominant sites of local tumour cell proliferation and accumulation in the peritoneal cavity. *Cancer Immunol. Immunother.* 47, 205–212
77. Arie, A.B. *et al.* (2013) The omentum and omentectomy in epithelial ovarian cancer: a reappraisal. Part II – the role of omentectomy in the staging and treatment of apparent early stage epithelial ovarian cancer. *Gynecol. Oncol.* 131, 784–790

78. Oosterling, S.J. *et al.* (2006) Insufficient ability of omental milky spots to prevent peritoneal tumor outgrowth supports omentectomy in minimal residual disease. *Cancer Immunol. Immunother.* 55, 1043–1051
79. Sorensen, E.W. *et al.* (2009) Omental immune aggregates and tumor metastasis within the peritoneal cavity. *Immunol. Res.* 45, 185–194
80. Cao, L. *et al.* (2014) The role of the CCL22-CCR4 axis in the metastasis of gastric cancer cells into omental milky spots. *J. Transl. Med.* 12, 267
81. Pradeep, S. *et al.* (2014) Hematogenous metastasis of ovarian cancer: rethinking mode of spread. *Cancer Cell* 26, 77–91
82. Cai, J. *et al.* (2012) Fibroblasts in omentum activated by tumor cells promote ovarian cancer growth, adhesion and invasiveness. *Carcinogenesis* 33, 20–29
83. Shan, T. *et al.* (2013) Fatty acid binding protein 4 expression marks a population of adipocyte progenitors in white and brown adipose tissues. *FASEB J.* 27, 277–287
84. Nieman, K.M. *et al.* (2011) Adipocytes promote ovarian cancer metastasis and provide energy for rapid tumor growth. *Nat. Med.* 17, 1498–1503
85. Zhang, L. *et al.* (2003) Intratumoral T cells, recurrence, and survival in epithelial ovarian cancer. *N. Engl. J. Med.* 348, 203–213
86. Wouters, M.C. *et al.* (2016) Treatment regimen, surgical outcome, and T-cell differentiation influence prognostic benefit of tumor-infiltrating lymphocytes in high-grade serous ovarian cancer. *Clin. Cancer Res.* 22, 714–724
87. Sato, E. *et al.* (2005) Intraepithelial CD8+ tumor-infiltrating lymphocytes and a high CD8+/regulatory T cell ratio are associated with favorable prognosis in ovarian cancer. *Proc. Natl. Acad. Sci. U. S. A.* 102, 18538–18543
88. Cancer Genome Atlas Research Network (2011) Integrated genomic analyses of ovarian carcinoma. *Nature* 474, 609–615
89. Tothill, R.W. *et al.* (2008) Novel molecular subtypes of serous and endometrioid ovarian cancer linked to clinical outcome. *Clin. Cancer Res.* 14, 5198–5208
90. Curiel, T.J. *et al.* (2004) Specific recruitment of regulatory T cells in ovarian carcinoma fosters immune privilege and predicts reduced survival. *Nat. Med.* 10, 942–949
91. Horikawa, N. *et al.* (2017) Expression of vascular endothelial growth factor in ovarian cancer inhibits tumor immunity through the accumulation of myeloid-derived suppressor cells. *Clin. Cancer Res.* 23, 587–599
92. Obermajer, N. *et al.* (2013) Induction and stability of human Th17 cells require endogenous NOS2 and cGMP-dependent NO signaling. *J. Exp. Med.* 210, 1433–1445
93. Viaud, S. *et al.* (2013) The intestinal microbiota modulates the anticancer immune effects of cyclophosphamide. *Science* 342, 971–976
94. Asquith, M. and Powrie, F. (2010) An innately dangerous balancing act: intestinal homeostasis, inflammation, and colitis-associated cancer. *J. Exp. Med.* 207, 1573–1577
95. Ikehara, Y. *et al.* (2008) Effective induction of antitumor immune responses with oligomannose-coated liposome targeting to intraperitoneal phagocytic cells. *Cancer Lett.* 260, 137–145
96. Sedlacek, A.L. *et al.* (2013) Generation of a dual-functioning antitumor immune response in the peritoneal cavity. *Am. J. Pathol.* 183, 1318–1328
97. Yokota, S.J. *et al.* (2013) Changes in ovarian tumor cell number, tumor vasculature, and T cell function monitored *in vivo* using a novel xenograft model. *Cancer Immun.* 13, 11
98. Armstrong, D.K. *et al.* (2006) Intraperitoneal cisplatin and paclitaxel in ovarian cancer. *N. Engl. J. Med.* 354, 34–43
99. Tamboli, R.A. *et al.* (2011) Reduction in inflammatory gene expression in skeletal muscle from Roux-en-Y gastric bypass patients randomized to omentectomy. *PLoS One* 6, e28577
100. Andersson, D.P. *et al.* (2017) Omentectomy in addition to bariatric surgery – a 5-year follow-up. *Obes. Surg.* 27, 1115–1118
101. Sdrailsis, E. *et al.* (2013) A prospective randomized study comparing patients with morbid obesity submitted to sleeve gastrectomy with or without omentectomy. *Obes. Surg.* 23, 965–971
102. Lima, M.M. *et al.* (2013) Visceral fat resection in humans: effect on insulin sensitivity, β -cell function, adipokines, and inflammatory markers. *Obesity* 21, E182–E189