Targeting B cells in atherosclerosis: closing the gap from bench to bedside

Running title: Targeting B cells in atherosclerosis

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Abbreviation list: Apoe: apolipoprotein E, LDL: low density lipoprotein, BAFF: B cell activating factor, BAFFR: B cell activating factor receptor, SLE: systemic lupus erythematosus, RA: rheumatoid arthritis

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Abstract

Atherosclerotic plaque formation is strongly influenced by different arms of the immune system, including B lymphocytes. B cells are divided in two main families, the B1 and the B2 cells. B1 cells are atheroprotective mainly via the production of natural IgM antibodies that bind oxidized LDL and apoptotic cells. B2 cells, which include follicular and marginal zone B cells, are suggested to be proatherogenic. Antibody-mediated depletion of B cells has become a valuable treatment option for certain autoimmune diseases, such as systemic lupus erythematosus (SLE) and rheumatoid arthritis (RA) that are also characterized by development of premature atherosclerosis. Thus, B cells represent a novel interesting target for therapeutic modulation of the atherosclerotic disease process. Here, we discuss the effect of different of B cell subsets in experimental atherosclerosis, their mechanism of action as well as potential ways to exploit these findings for the treatment of human disease.

Immunity and atherosclerosis

Atherosclerosis is a multifactorial disease with multiple genetic and environmental risk factors and is characterized by formation of a plaque in the artery wall. Plaque formation is initiated upon trapping of low density lipoproteins (LDL) in the intima where they undergo oxidation and acquire immunogenic properties. The oxidation of LDL results in the generation of many different immunogenic epitopes – termed oxidation-specific epitopes - that are recognized by both innate and adaptive immune mechanisms. Monocytes that enter the intima differentiate to macrophages and take up oxidized LDL (OxLDL), which leads to their activation and results in the formation of foam cells. During this process, macrophages are stimulated by lipid-derived danger associated molecular patterns (DAMPs) such as oxidized phospholipids that promote cytokine secretion via scavenger receptor CD36 and TLR signaling and cholesterol crystals, which activate the inflammasome followed by IL-1β production. [1, 2] Plaque inflammation is further amplified and sustained as a result of recruitment/activation of the adaptive immune system and is an important and potentially central driving force in promoting vulnerable plaque features. Plaque rupture results in life threatening manifestations such as myocardial infarction and stroke. Surgery and reducing the risk of clotting are powerful end-stage solutions and lipid lowering is an effective preemptive treatment. However, significant risk remains and new strategies to target underlying causes of vulnerable plaque development and rupture are important future goals.[3] Although an adaptive immune system is not essential for atherosclerosis to develop,[4, 5] many studies now demonstrate that it has a diverse range of important site-specific influences on plaque development and inflammation. (Auto)immune reactivity to a range of autoantigens, but most prominently modified low density lipoprotein (LDL), is a mark of human cardiovascular disease and in experimental models plays a significant role in promoting atherosclerotic plaque progression. Atherosclerosis is a distinct case compared to typical autoimmune diseases since 1) the major autoantigen OxLDL is really a modified self antigen or neo-self antigen, and 2) the OxLDL “auto”-antigen, rather than playing a physiological function, is pathogenic and disease-causing. There are also other autoantigens involved, such as heat shock protein 60 [6, 7], and the impact of other autoimmune diseases in promoting atherosclerosis such as RA and SLE is well known.[8, 9] The role of T cells and IFNγ-secreting Th1 cells in particular as key drivers of plaque inflammation is well documented, and experimental approaches to dampen these responses by enhancing the activity of regulatory T cells are being tested. More recently, it was found that B cells could also play both protective and pathogenic roles, and studies from animal models that have been extensively reviewed elsewhere,[10, 11] are beginning to dissect the different pathogenic and protective B cell responses. Here, we will discuss these insights in light of translational aspects.

B cell development, subsets and functions

B cells are defined by their unique expression of surface (B cell receptors) and secreted (antibody) immunoglobulin, produced from multigenic loci somatically rearranged during B cell development, giving each B cell clone a BCR with a different specificity [12, 13]. Two major types of B cells, B1 and B2 cells, develop from hematopoietic stem cells (HSCs). B1 cells develop from fetal liver HSCs and are subsequently maintained in the periphery via self-renewal, which is dependent on the spleen.[14-16] B2 cells have a half-life of only a few days and are continually replaced from bone marrow HSCs. Only B cell clones encountering antigens, or in some cases in response to innate signals, become activated and persist. These differentiate into antibody-secreting plasma cells, or alternatively resting memory B cells, that respond more rapidly to subsequent antigen encounters. B1 cells are further divided into B1a, which express the CD5 on their surface and B1b cells. Both B1a and B1b cells primarily patrol peritoneal and pleural niches, and form a major (50%) proportion of peritoneal B cells in mice,[17] but only a minor population (<5%) in the spleen. B2 cells recirculate through the blood and lymphatics, encountering antigens in secondary lymphoid

organs – the spleen, lymph nodes and Peyer's patches. Both B1 and B2 derived plasma cells are primarily found in the spleen and bone marrow,[17] suggesting the existence of common plasma cell niches allowing antibodies quick access to the blood. In cases of chronic inflammation such as atherosclerosis, tertiary lymphoid organs (TLOs) develop adjacent to diseased tissue, the arterial adventitia in the case of atherosclerosis, and may become major sites of adaptive immune activation.[18-20] It is likely that TLOs accumulate B cells with relevant antigen specificity,[21] or B cell subsets that exhibit specific properties for example circulating capacity.[22]

The workload of responding to different antigens is divided between different B cell subsets. Responses are traditionally divided into T cell dependent, those requiring helper T cell signals (in addition to the antigen and antigen-specific B cell) and T cell independent responses, with several subtypes of responses within each group now recognized.[23] B1 cells produce natural antibodies to common microbial epitopes and (neo)self-determinants such as oxidation-specific epitopes independent of cognate T cell help.[24] Multiple types of T cell-independent responses are now recognized, including those to TLR ligands such as bacterial polysaccharides. Marginal zone (MZ) B cells, which differ from other B2 cells in only the final stages of their development, also contribute to innate antibody production. They can respond to multiple antigen types and their location in the marginal zone of the spleen provides them with the ability to respond rapidly to blood-borne antigens.[25] Follicular B2 cells, which form the majority of recirculating mature B cells, respond to protein antigens presented to them complexed with Ig or complement and often immobilized on the surface of innate immune cells. These responses are T cell-dependent. Upon interaction with an antigen-specific T helper cell at the follicular-T cell zone border of SLOs, B2 cells migrate along with the T cell into the follicle and proliferate, forming germinal centers, where they undergo antibody isotype class- switching i.e. from IgM to IgG, IgA or IgE, and affinity maturation through natural selection by competition for antigen and T cell help.[26] In addition to antibody secretion, B cells can also be key sources of cytokines and chemokines. Production of GM-CSF by innate response activator B cells (IRA), a subset related to B1 cells, is important for dendritic cell activation [27] and B cell secretion of Ccl7 (MCP-3) is a key regulator of monocyte mobilization after acute myocardial infarction.[28].

B1 and B2 cells also display different survival properties. Mature B2 cell survival is dependent on B cell activating factor receptor (BAFFR) signaling. BAFFR signaling prevents B2 cell apoptosis by binding the BAFF ligand. BAFF is mainly produced by stromal cells as well as by macrophages, monocytes, dendritic cells and activated T cells [29, 30] BAFF is recognized by two other receptors named transmembrane activator and calcium modulator and cyclophilin ligand interactor receptor (TACI) and B cell maturation antigen (BMCA), both of which also bind a second ligand of the so called BAFF system, named a proliferation inducing ligand (APRIL), which has been shown to facilitate IgA class switching [31]. TACI receptor has been shown to mediate antibody class switching in mature B cells, whereas BCMA is essential for plasma cell survival. Disruption of BAFFR signaling, for example by genetic deletion of BAFF or BAFFR, leads to mature B2 cell apoptosis, whereas B1 cell numbers remain unaltered. Interestingly, IRA B cells are also depleted in BAFFR deficient mice, despite the fact that they are B1 cell derived.[32]

Our increased understanding of the diversity of B cell functions has reignited research into B cell regulation of atherosclerosis.

B cells are modulators of atherosclerosis

The role of B cells in murine atherosclerosis was first investigated by Caligiuri et al, who showed that accelerated atherosclerosis upon splenectomy was reversed by adoptive transfer of splenic B cells isolated from either wild type or apolipoprotein E deficient mice (*Apoe*$^{-/-}$). Notably, the latter had a stronger atheroprotective effect (below the sham operated mice) indicating that B cells acquire increased or even novel atheroprotective properties in hypercholesterolemic conditions.[33] The results of this study were supported by Major et al

who performed B cell deficient (μ*MT*) bone marrow transfer into lethally irradiated low density lipoprotein receptor deficient mice (*Ldlr*$^{-/-}$) that led to enhanced atherosclerotic plaque formation upon atherogenic diet feeding.[34] Collectively these data suggested an overall protective role of B cells in atherosclerosis. However, as described above, B cells are very heterogeneous and consist of several cell subsets with different localization properties, activation requirements, survival characteristics and immunoglobulin secretion profile. Thus, different B cell subsets may have different or even opposing roles in atherogenesis, and the understanding of this is critical for the optimal development of B cell targeting therapies.

We and others have investigated the effect of anti-CD20 antibody treatment in experimental atherosclerosis. Anti-CD20 treatment, which preferentially leads to B2 cell depletion, while B1a cells remain nearly intact, reduced atherosclerosis in atherogenic diet fed *Apoe*$^{-/-}$ and *Ldlr*$^{-/-}$ mice.[35, 36] In agreement with an effect that depends on B2 cell depletion, adoptive transfer of splenic B2 cells into lymphocyte-deficient Rag2$^{-/-}$γ-chain$^{-/-}$*Apoe*$^{-/-}$ or B cell deficient μMT/*Apoe*$^{-/-}$ mice aggravated atherosclerosis in two studies from one group, whereas another showed a protective effect[22, 36] emphasizing the need for alternative models. Further evidence on the proatherogenic role of B2 cells, came from studies on the role of BAFFR deletion in atherosclerosis prone mice. BAFFR deficient *Apoe*$^{-/-}$ mice as well as BAFFR deficient *Ldlr*$^{-/-}$ bone marrow chimeric mice, which lack mature B2 cells, developed decreased atherosclerosis.[37, 38] Similar data were obtained by Kyaw et al who treated atherogenic diet fed *Apoe*$^{-/-}$ mice with a blocking anti-BAFFR antibody.[39] The mechanism by which B2 cell depletion protects mice from atherosclerosis is not entirely clear. Of note, anti-CD20 treatment failed to protect western diet fed *Apoe*$^{-/-}$ mice that were co-treated with a neutralizing antibody against IL-17 suggesting that Th17 responses may be involved in the protective mechanism of anti-CD20 treatment. Moreover, though in anti-CD20 treated mice the prototypic natural IgM antibody T15/E06 that binds OxLDL was largely unaffected, both total and anti-OxLDL specific IgG titers were dramatically reduced.[35] This is particularly interesting, as previous epidemiological and experimental data point to proatherogenic role of IgG antibodies.[40] For example, IgG antibodies to ApoB100 have been suggested to promote atherosclerosis in mice.[41] Alternatively, the proatherogenic role of B2 cells may be due to their capacity for IgE antibody production. IgE antibodies have been shown to be elevated in CHD patients compared to healthy individuals [42] and to be a prognostic maker for myocardial infarction in the Helsinki Heart study.[43] Supporting experimental evidence on the proatherogenic role of IgE antibodies comes from Wang et al who investigated the role of the high affinity receptor of IgE (FcεRI) in atherogenic diet fed *Apoe*$^{-/-}$ mice. FcεRI deficient *Apoe*$^{-/-}$ mice developed reduced atherosclerosis and plaque complexity.[42] Whether these might constitute an underlying mechanism by which B2 cells promote atherosclerotic plaque formation remains to be shown.

In contrast to Kyaw et al,[36] Doran et al found that adoptive transfer of splenic B2 cells from *ApoE*$^{-/-}$ mice reduced atherosclerosis in cholesterol-fed μMT/*Apoe*$^{-/-}$.[22] Possible explanations for this discrepancy may include different cell ratio of follicular and MZ B cells or B2 cell purity of these cell preparations. In addition, Kyaw et al transferred 5x10^6 whereas Doran et al transferred 3x10^7 or 6x10^7 B2 cells into B cell deficient mice. Based on the fact that BCR interaction with self antigens strongly controls the developmental fate and survival of B cells,[44] one may hypothesize that difference in the number of transferred B2 cells into B cell deficient mice, impacts the way the cells interact with the endogenous self antigen pool. Thus, dependent on their numbers, transferred B cells may acquire distinct phenotypes and undergo distinct responses to those normally occurring in B cell-sufficient mice. Notably, Doran et al suggest that local B cell responses in the adventitia of affected arteries, at least after B cell transfer, may be protective, whereas the localization of the pathogenic transferred B cells in two other studies was not defined. In conclusion B2 cells seem to be proatherogenic though additional studies on the role of each B2 cell subset would provide more conclusive evidence on their role in atherosclerosis.

On the other hand, the data on B1a cells are more robust and suggest a strong atheroprotective role. Kyaw et al showed that splenectomy of *Apoe*$^{-/-}$ mice - which results in accelerated atherosclerosis - leads to nearly 50% reduction of B1a cells in the peritoneum

followed by a strong decrease in plasma IgM titers. Moreover, adoptive transfer of peritoneal B1a cells into splenectomized *Apoe*$^{-/-}$ recipients fed an atherogenic diet, reduced atherosclerosis even beyond the disease-accelerating effect resulting from splenectomy. This was dependent on the capacity of B1a cells to secrete natural IgM antibodies as there was no protective effect when the splenectomized *ApoE*$^{-/-}$ mice received B1a cells isolated from secreted IgM deficient donor mice.[16] Natural IgM antibodies (NAbs) have been shown to be atheroprotective.[40] Lewis et al, demonstrated that *sIgM*$^{-/-}$ crossed onto *Ldlr*$^{-/-}$ background develop strongly accelerated atherosclerosis when fed regular chow or atherogenic diet.[45] The atheroprotective capacity of natural IgM may be to a large extent mediated by the IgM with specificity for oxidation-specific epitopes (OSE). We have previously shown that a large part of B1 cell derived natural IgM antibodies is directed against OSE, which are major antigenic determinants on the surface of apoptotic cells and on OxLDL. OSE-specific natural IgM have the potential to neutralize proinflammatory effects of OxLDL, inhibit foam cell formation and promote clearance of apoptotic cells. A protective role for OSE-specific IgM is also supported by epidemiological data, which show that anti-OxLDL specific IgM antibodies are inversely associated with CVD adverse effects.[40] Thus strategies that would promote the expansion of atheroprotective natural IgM antibodies may be beneficial in human atherosclerosis.

The recently identified IRA B cells[32] also play a role in atherosclerosis. IRA B cell deficient *Ldlr*$^{-/-}$ mice, which were generated by reconstitution with GM-CSF and B cell deficient bone marrow, developed reduced atherosclerosis in the entire aorta. These mice had a strong reduction in IFNγ secreting CD4^{+} T cells and anti-OxLDL IgG2c specific antibodies.[27] Because IRA B cells are depleted in BAFFR deficient mice,[32] this could be an alternative mechanism by which neutralization of BAFFR signaling protects from atherosclerosis.

A critical role of B cells in human atherosclerosis has been suggested by the finding that several critical genes involved in survival, proliferation or activation status of B cells, were identified as key drivers of CHD based on an integrated analysis of whole blood gene expression profiles from Framingham Heart Study participants and data from genome wide association studies (GWAS).[46] In line with this it has recently been shown that increased numbers of a B cell subset identified as CD19^{+}CD86^{+} associate with increased risk for stroke but not with coronary artery disease.[47] Thus, developing or exploiting existing therapeutic approaches that modulate the survival or activation status of B cells may provide a novel line of treatment in atherosclerosis.

Targeting B cells in atherosclerosis and myocardial infarction

B cells along with the antibodies they produce promote the pathology of several autoimmune disorders such as rheumatoid arthritis (RA) and systemic lupus erythematosus (SLE).[48] Interestingly, both RA and SLE patients are characterized by increased risk of CVD complications, mainly ischemic heart disease, which is associated with the development of premature atherosclerosis.[49] Accelerated atherosclerosis in SLE and RA patients seems to be independent of classical Framingham risk factors such as age, total cholesterol, HDL and systolic blood pressure. This suggests that aggravated atherosclerosis in these patients may be a result of increased inflammation and altered immune responses, such as autoantibody production. For example, SLE patients have been found to develop autoantibodies against apolipoprotein A-I, which have been associated with acute coronary syndromes.[9]

The development of B cell targeting therapeutics for RA and SLE has gained a lot of attention in the last years. The first B cell therapeutic agent that has been approved for clinical use in RA patients is the anti-CD20 antibody (Rituximab). Rituximab cross links the CD20 receptor present on all B cells, leading to Fcγ mediated cell depletion and consequently to decreased immunoglobulin/autoantibody titers.[50] Another B cell depleting agent, a blocking antibody against BAFF (Belimumab) has been approved by the FDA in 2011 for clinical use in SLE patients, who have been shown to have increased plasma BAFF

levels.[30] Belimumab, which is the first drug approved for SLE in 50 years, blocks soluble BAFF from binding to its receptor (BAFFR) resulting in apoptosis of mature B cells. SLE patients treated with Belimumab show an improvement of clinical score [51], which was associated with reduced B cell numbers as well as reduced total immunoglobulins and autoantibody titers against dsDNA.[52] As mentioned above, anti-CD20 mediated depletion of B cells as well as BAFFR deficiency or treatment with an anti-BAFFR antibody has been found to reduce plaque burden in atherosclerosis prone mice.

We have recently also shown that B cell derived CCL7 (MCP-3) drives monocyte mobilization leading to enhanced tissue injury in a mouse model of myocardial infarction. Treatment with an anti-CD20 or an anti-BAFF antibody which lead to B cell depletion and B cell derived CCL7 reduction, reduced infarct size and improved cardiac remodeling.[28] Thus, it can be speculated that Rituximab or Belimumab treated patients may also have a better outcome upon myocardial infarction.

Besides anti-CD20 and anti-BAFF antibodies, additional B cell targeting agents are being developed that may have the potential to modulate atherosclerotic lesion formation as well. In line with this, a decoy form of the TACI receptor (TACI-Ig/Atacicept) has been tested in clinical phase II/III trial as treatment for SLE patients. The results suggest a protective effect of Atacicept treatment in SLE at a high dose, though the recruitment of patients and treatment in this group was terminated prematurely due to two sudden deaths.[53] Combined neutralization of BAFF and APRIL upon TACI-Ig treatment, results in depletion of plasma cells and mature B cells as well as strong antibody level reduction in mice.[54, 55] Although TACI-Ig could be considered as a therapeutic option in atherosclerosis, given its B cell depleting properties, one should keep in mind that this treatment also strongly reduces IgM titers[54], which have a protective effect in atherosclerosis.

Additional B cell modulating agents that are tested as treatment for SLE and RA patients include anti-CD19 and anti-CD22 antibodies. CD19 is a B cell specific surface marker and is involved in the formation of the B cell receptor complex as well as in its activation. [56] In contrast to CD20, a subset of plasma cells expresses CD19. Thus, targeting CD19 could also result in depletion of $CD19^+$ antibody producing plasma cells and in more efficient plasma IgG reduction but -similar to TACI-Ig-, anti-CD19 treatment may result in decrease of atheroprotective IgM titers as well. An antibody against CD19 named MDX1342 is in clinical trial as treatment of RA patients.[57] CD22 is a transmembrane sialoglycoprotein and is expressed by the majority of mature B cells and is a negative modulator of B cell receptor signaling. Epratuzumab is a humanized antibody (clinical phase III trial for SLE patients) that binds CD22 induces its internalization and phosphorylation. Apart from the moderate B cell depleting capacity (mainly $CD27^-$ B cells), Epratuzumab exhibits immunomodulatory properties such as inhibition of B cell proliferation, *in vitro*.[57, 58] In mice, CD22 deficiency results in strongly reduced MZ B cells,[59] thus investigation of the impact of CD22 deficiency could help to elucidate the role of different B2 cells in atherosclerosis. Finally, neutralizing IgE antibodies for example by using Omalizumab (an FDA approved human anti-IgE antibody that neutralizes free IgE antibodies) may be an alternative more specific approach of limiting a B cell mediated pro-atherogenic mechanism in selective settings. Interestingly, IgE antibodies have been recently shown to be involved in the pathogenesis of SLE [60].

All above mentioned B cell depleting therapeutic approaches are also characterized by the risk of compromising immunity in general with an increased risk of infections and presumably cancer development as well as decreased responsiveness to vaccination. Moreover, different B cell depletion strategies have also been found to result in different therapeutic efficacy. For example, treatment of SLE patients with Rituximab showed no clinical benefit in two double blind phase II/III clinical trials, despite the fact that it is a very efficient B cell depleting agent that should be beneficial in SLE patients given the protective effect of Belimumab. One may speculate that interfering with the BAFF-BAFFR signaling results in additional effects on top of B cell depletion. For example, BAFF stimulation of human monocytes, induces surface expression of TACI and promotes cell survival.[61] The effects of anti-CD20 treatment or the consequences of interfering with BAFF-BAFFR

signaling on CVD in humans are not known, and only detailed understanding of the role of B cells and the BAFF system will help the identification of the best therapeutic option for CVD.

Summary and Outlook

In addition to the use of genetic models resulting in B cell deficiencies, the treatment of mouse models of atherosclerosis with B cell depleting agents has provided more information on the role of different B cells in plaque formation. For example, anti-CD20 treatment or blockage of the BAFFR signaling pathway that results in B2 cell depletion protects mice from atherosclerosis. It is particularly interesting that similar B cell depletion strategies are approved as treatments in autoimmune diseases such as SLE and RA that are associated with increased risk of cardiovascular disease due to the development of accelerated atherosclerosis. Therefore, studies monitoring the effects of Rituximab and Belimumab treatment (and of other B cell targeting agents that are being developed) on CVD would be highly important for the understanding of the role of B cells in human atherogenesis and the potential of B cell targeting therapeutic strategies.

Significance

It is clear that some B cell responses promote atherosclerosis whereas others are protective. Natural antibody secretion from the B1a cell subset is a major protective pathway, but which types of B cell responses or functions are most pathogenic is unclear. To study this in more detail is critical since:

- Understanding the critical components specific to pathogenic B cell responses will inform future therapeutic strategies against atherosclerosis.
- B cell responses are complex and it is important to understand which specific pathways and components are pathogenic rather than protective.
- Many autoimmune disease patients at high risk for cardiovascular disease are being treated by B cell-targeting therapies.
- There are diverse opportunities to target B cells and many existing therapies used in autoimmune diseases and cancer could be translated for use in cardiovascular disease, and the previous successes of this mode of intervention bode well for future therapeutic developments

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Figure Legends

Figure 1. Role of different B cell subsets in murine atherosclerosis. B cells consist of two major cell subsets, named B1 and B2 cells, which are characterized by different localization properties and activation requirements. B1 cells reside predominately in the peritoneum and are sub-divided into B1a and B1b. B1a cells protect from atherosclerosis. Their atheroprotective properties depend mainly on the capacity to produce OxLDL specific natural IgM antibodies – which can be enhanced by IL-5 stimulation - that block OxLDL uptake and foam cell formation. In addition natural IgM have also been shown to promote apoptotic cell clearance. The role of B1b in atherosclerosis remains still elusive. B2 cells are mainly found in the spleen and consist of marginal (MZ) and follicular (FO) B cells. B2 cells seem to be proatherogenic. Although the underlying mechanism is yet to be identified, this may include production of proatherogenic IgG and IgE antibodies. Innate response activator B cells (IRA), which are characterized by GM-SCF secretion, promote the expansion of IgG2c anti-OxLDL antibodies and aggravate atherosclerosis. Mph: macrophage, BCR: B cell receptor, TCR: T cell receptor, BAFFR: B cell activating factor receptor, DC: dendritic cell, MHC: major histocompatibility complex.

Figure 2. Biologicals that target B cells and their effect on murine atherosclerosis. Anti-CD20 antibodies cross-link the surface CD20 receptor on B cells, resulting in Fcγ mediated depletion of predominantly B2 cells. Plasma IgM titers are moderately reduced whereas IgG titers are strongly decreased following anti-CD20 treatment. Atherosclerosis-prone mice injected with anti-CD20 antibody develop reduced atherosclerotic plaque size. In contrast to B1 cells, B cell activating factor (BAFF) signaling via the B cell activating factor receptor (BAFFR) is essential for B2 cell survival. Treatment with a neutralizing antibody against BAFF leads to B2 cell apoptosis followed by strong reduction in plasma IgG titers. Combined neutralization of BAFF and a proliferation inducing ligand (APRIL) upon treatment with the extracellular domain of the transmembrane activator and calcium modulator and cyclophilin ligand interactor receptor (TACI) fused to an Ig backbone (TACI-Ig) results in reduced numbers of B2 and to lesser extent of B1 cells. Moreover, TACI-Ig treatment inhibits plasma cell survival followed by reduction in total Ig plasma titers. The effect of both anti-BAFF and TACI-Ig treatment in atherosclerosis remains to be shown. Finally, IgE antibodies have been suggested to promote atherosclerotic plaque development and to correlate with CVD risk. The effect of IgE antibody blockage via anti-IgE treatment in atherosclerosis is yet to be investigated. IRA: innate response activator B cells.

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