Chronic inflammation: tissue recovery versus disease progression

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ABSTRACT

Chronic inflammation, atherosclerosis and cancer are leading causes of death in industrialized society. Epidemiological studies have shown that chronic inflammation predisposes individuals to certain cancers, while anti-inflammatory and anti-oxidant agents may protect against cancer development and metastasis. Inflammation supports the different phases of cancer development through the inflammatory molecules produced by infiltrating immune cells, resident stromal cells and even cancer cells. Although atherosclerosis has been considered to be multi-factorial disease, in which genetic and environmental factors have been implicated, inflammation also significantly contributes to plaque formation and progression, and to stenosis of atherosclerotic lesions. Major nuclear transcription factors and molecular mediators of inflammation that induce altered cell expression of adhesion molecules, proteases, and growth factors are common factors in the microenvironment leading to disease development and progression of both atherosclerosis and cancer. Important pathogenic pathways on atherosclerosis and cancer follow endothelial cell dysfunction and the activation of the hemostatic system and angiogenesis via inflammation-dependent mechanisms represent important features of this dysfunction. Therefore, novel target-oriented therapies affecting altered mechanisms of inflammation, angiogenesis and tissue proliferation may similarly inhibit atherosclerosis and cancer. Main treatment strategies include reducing oxidative stress; inhibiting chemokine, cytokine, and growth factor cell signal transmitt; down-regulating excess matrix digestion; inactivating nuclear factor-kappa B signal pathway, and interfering with cell cycle regulation.

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Inflammation in the molecular pathogenesis of cancer and atherosclerosis

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La inflamación en la patogenia molecular del cáncer y la arteriosclerosis

Las enfermedades inflamatorias crónicas, la arteriosclerosis y el cáncer están entre las primeras causas de muerte en la sociedad industrializada. Estudios epidemiológicos han demostrado que las enfermedades inflamatorias crónicas predisponen a la aparición de ciertos cánceres, mientras que algunos agentes antiinflamatorios y antioxidantes protegen frente al desarrollo del cáncer y su metástasis. La inflamación facilita diferentes fases del desarrollo del cáncer, a través de moléculas producidas por células del sistema inmunitario infiltrantes de los tumores, por células del estroma tumoral e, incluso, por las propias células tumorales. Aunque la arteriosclerosis se ha considerado como una enfermedad de etiología multifactorial, en la que están implicados factores genéticos y ambientales, la inflamación también contribuye a la formación y el desarrollo de la placa e, incluso, la estenosis vascular en las propias lesiones arterioescleróticas. Los principales factores nucleares de transcripción y mediadores moleculares de la inflamación que alteran la expresión de moléculas de adhesión, proteasas y factores de crecimiento, son factores habituales del microambiente que conduce al desarrollo de la arteriosclerosis y el cáncer. De hecho, sus rutas patogénicas más importantes dependen de alteraciones del endotelio vascular y la activación del sistema hemostáticos y la angiogénesis a través de mecanismos inflamatorios. Por consiguiente, los nuevos tratamientos orientados a dianas moleculares específicas, que afectan a mecanismos alterados de inflamación, angiogenicidad y proliferación tisular, podrían inhibir igualmente la arteriosclerosis y el cáncer. Entre las principales estrategias a considerar están la disminución del estrés oxidativo, la inhibición de algunas quimiocinas, citocinas y transductores intracelulares de factores de crecimiento, la regulación negativa de la digestión de matriz extracelular, la inactivación del factor nuclear kappa B, y la interferencia de reguladores del ciclo celular.

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Chronic inflammation: tissue recovery versus disease progression

Chronic inflammation has been implicated in the pathogenesis of autoimmunity, atherosclerosis, and cancer. Inflammation is the initial response of the body to harmful stimuli and is achieved by the increased movement of plasma and leukocytes from the blood into the injured tissues. A cascade of biochemical events propagates and strengthens the inflammatory response, involving the local microvascular system, the immune system, the connective tissue and parenchymal cells within the microenvironment of injured tissue. The recovery of the acute phase of inflamed
tissue is involved with the following processes: First, inflammatory factors with proangiogenic effects—for instance vascular endothelial growth factor (VEGF)—are upregulated in the inflamed tissues in order to stimulate new blood vessel development, which in turn increases blood infusion to the damaged tissue. This process is crucial for the supply of oxygen, nutrients and leukocytes to the lesion area that needs tissue repair and healing. Second, part of the protective mechanisms of the body against antigens and pathogens in the inflamed tissue is the release of reactive oxygen species (ROS) in order to harm pathogens. Third, replacement of necrotic and apoptotic tissue cells through the activation of cell proliferation and regeneration via massive release of growth factors that enhance signal transduction processes. These three processes are mediated by activated neutrophils, monocytes and endothelial cells, which are the major cell populations supporting the proinflammatory response at inflamed tissues.

Prolonged inflammation, also known as chronic inflammation, leads to simultaneous destruction and healing of the affected tissue and to the progressive shift in the type of cells that are present at inflammatory sites. Therefore, although inflammation is central to our fight against pathogens, if it is not ordered and timely, the resulting chronic inflammation can contribute to diseases such as heart attacks, arthritis and Alzheimer’s disease. Chronic inflammation has also become a recognized risk factor for carcinogenesis and can be caused by sustained infection, autoimmune disorders and other pathologies. It results in the infiltration of inflammatory cells at specific sites in the body, including macrophages, T and B cells, natural killer cells, neutrophils and other granulocytes. T cells and macrophages are the predominant inflammatory cells and they excrete large amounts of inflammatory cytokines, proangiogenic factors and reactive oxygen species (ROS) into the microenvironment.

Angiogenesis, secretion of ROS and growth factor-dependent tissue regeneration are the outcome of the activation of both leukocytes and endothelial cells, and have beneficial effects during the acute phase of inflammation. However, during chronic inflammation, the same processes can become very harmful. Increased blood supply, which brings oxygen and nutrients in the presence of a lot of growth factors, can trigger uncontrolled cell division; massive ROS release can damage DNA and subsequently can give rise to mutated transformed cells; and the stimulation of proliferative signal transduction pathways via massive release of growth factors can support not only regeneration and healing of normal tissue, but also transformed cell development.

Angiogenesis in the chronic inflamed tissue is a consequence of at least two different mechanisms: The first is proangiogenic factor secretion by pathogen-activated monocytes and neutrophils. These two cell types, upon triggering with endotoxins or cytokines such as IL-1beta, secrete proinflammatory and proangiogenic factors such as VEGF. The second is the release of proangiogenic factors by endothelial cells at the inflamed tissue. Under conditions of injury, infection, or chronic inflammation, endothelium is exposed to agonists such as endotoxin, thrombin, and heparan sulfate, and in response, it expresses both plasminogen activator inhibitor 1 (PAI-1), which promotes coagulation; and E-selectin, interleukins (IL-1 and IL-6) and chemokines (IL-8), which further stimulate inflammation. This microvascular activation was first described in endothelial cells exposed to endotoxins, such as LPS; and cytokines, such as IL-1, TNFalpha or IL-6. Endotoxins activate endothelial cells by stimulating toll-like receptor 4 (TLR4), and IL-1 stimulates one or more of several IL-1 receptors (IL-1R). In turn, TLR4 and IL-1R invoke well-known intracellular signaling pathways that activate NF-kappaB, a transcriptional regulator that orchestrates expression of proinflammatory and proangiogenic genes in endothelial cells. The activation of TLR4 and IL-1 receptors on immune and endothelial cells leads to the secretion of proangiogenic cytokines, such as VEGFα and VEGFB, in turn acting on VEGFR1-, VEGFR2- and VEGFR3-expressing cells to promote new blood vessel formation at the inflamed tissues.

The fibrinolytic system—represented by the cellular receptor of urokinase uPAR, urokinase (uPA) and its specific inhibitor PAI-1—can also promote cancer progression and metastasis.

Inflammatory cytokines not only upregulate PAI-1 but uPA also activates NFKappaB via IKK. There is a link between the uPAR/uPA/PAI-1 system and inflammation-dependent tumor initiation and progression. These inflammatory matrix proteins are responsible for the altered composition of the inflammatory matrix containing large amounts of PAI-1. Urokinase is also a plasminogen activator that transforms the zymogen plasminogen into the active protease plasmin. Plasmin in turn can degrade the extracellular matrix and activate other proteins (i.e. pro-metalloproteases and pro-growth factors). In human tumors, the excessive expression of uPA and uPAR is a marker for an unfavorable clinical outcome. Moreover, in human tumor xenografts, uPAR blockade inhibits cancer growth and metastasis. The uPAR/uPA/PAI-1 system is also involved in VEGF-induced angiogenesis, thereby further contributing to tumor progression. Finally, a variety of uPAR interactors such as integrins, growth-factor receptors, G-protein coupled receptors, members of the LDL receptor family and vitronectin appear to induce cancer cell phenotype. Altogether, fueled by inflammation the uPAR/uPA/PAI-1 system in turn influences tumor initiation and progression via several pathways that can also become targets for inhibition.

### Inflammation in cancer development and metastasis

There is a poorly understood, but longstanding, observation and epidemiologic link between inflammation and cancer. It was in 1863 that Rudolf Virchow reported for first time leucocytes in neoplastic tissues and made a connection between inflammation and cancer. He suggested that the "lymphoreticular infiltrate" reflected the origin of cancer at sites of chronic inflammation. Recent estimates suggest that about 20% of all human cancers are caused by chronic infection or chronic inflammatory states. Prominent examples for this phenomenon are the strong associations between chronic gastritis, hepatitis, prostatitis or colitis and increased risk of primary carcinoma in the corresponding organ. Almost 30% of people who suffer from inflammatory bowel disease will develop colorectal cancer, and around 18% of people who suffer from inflammation of the prostate will develop prostate cancer. Similar numbers exist for the development of liver cancer from hepatitis. Therefore, the development of cancer cells from chronic inflamed tissues is a major problem in the world.

It has been suggested that chronic inflammation supports the different phases of tumor development, i.e. initiation, promotion and progression. Inflammatory molecules that are produced by resident tissue cells and infiltrating defense cells, including macrophages, lymphocytes, natural killer cells, neutrophils, dendritic cells and eosinophils, in part provide this support. For instance, Helicobacter pylori-induced gastritis is associated with gastric carcinoma and gastric B-cell lymphoma. Chemokines induced by H. pylori attract B-cells to the mucosa where they become targets for the carcinogenic process that can occur during the chronic inflammatory process. However, biochemical processes in chronic inflamed tissues that are responsible for the development of cancer are still unclear. The transformation of chronic inflamed tissue into cancerous tissue is a process comprising of at least three stages. The first stage is the
On the one hand, cytokines. Endothelial dysfunction is characterized by decreased nitric oxide synthesis, local oxidation of circulating lipoproteins and their entry into the vessel wall. Intracellular ROS, similarly induced by the multiple atherosclerosis risk factors, lead to enhanced oxidative stress in vascular cells and further activate intracellular signaling molecules involved in gene expression. Upregulation of cell adhesion molecules facilitates adherence of leukocytes to the dysfunctional endothelium and their subsequent transmigration into the vessel wall. The evolving inflammatory reaction is instrumental in the initiation of atherosclerotic plaques and their destabilization, and, therefore, inflammation is considered to play an important role in the progression of atherosclerosis and artery plaque destabilization, converting a chronic process into an acute disorder with ensuing thrombo-embolism. 

Inflammation in atherosclerosis

Atherosclerosis has been viewed to reflect the deposition of lipids within the vessel wall of medium-sized and large arteries. Despite the fact that the association between LDL cholesterol and atherosclerosis has been evident for at least three decades, our understanding of exactly how LDL precipitates atherosclerosis is still unclear. Now this concept has changed and it is assumed that a complex endothelial dysfunction induced by elevated and modified low-density lipoproteins, free radicals, infectious microorganisms, shear stress, hypertension, toxins after smoking, or combinations of these and other factors, can lead to a compensatory inflammatory response. Endothelial dysfunction is characterized by decreased nitric oxide synthesis, local oxidation of circulating lipoproteins and their entry into the vessel wall. Intracellular ROS, similarly induced by the multiple atherosclerosis risk factors, lead to enhanced oxidative stress in vascular cells and further activate intracellular signaling molecules involved in gene expression. Upregulation of cell adhesion molecules facilitates adherence of leukocytes to the dysfunctional endothelium and their subsequent transmigration into the vessel wall. The evolving inflammatory reaction is instrumental in the initiation of atherosclerotic plaques and their destabilization, and, therefore, inflammation is considered to play an important role in the progression of atherosclerosis and artery plaque destabilization, converting a chronic process into an acute disorder with ensuing thrombo-embolism.

During atherosclerosis, T cells and macrophages infiltrate the vessel wall triggered by endothelial dysfunction, and locally interact in a synergistic manner. Auto-reactive T cells recognize oxLDL, heat shock proteins and share microbial antigens by molecular mimicry and release proinflammatory cytokines. Macrophages on stimulation by T-cell-derived cytokines and transformation into foam cells after uptake of oxLDL, also secrete matrix metalloproteases predisposing the plaques to subsequent rupture. Plaque-associated macrophages, moreover, are an important cellular source of tissue factor. Finally, on plaque rupture, tissue factor-rich plaque material gets in contact with the circulation and activates the extrinsic coagulation pathway.

The fact that proinflammatory cytokines are instrumental in the progression of atherosclerosis, as revealed by numerous animal studies and suggested by their expression in atherosclerotic human plaques, opens the therapeutic prospect of targeting cytokine expression and cytokine-signaling proteins. In experimental settings, blockade of IFN-gamma and TNFalpha ameliorates atherosclerosis development. Pentoxifylline—a TNF antagonist—inhibits plaque formation in apoE−/− mice by shifting T cells toward T-helper-2 differentiation, characterized by increased production of immune suppressant cytokine IL-10. As another approach, inhibitors of matrix metalloprotease activity and suppressors of cytokine signaling proteins can also ameliorate cytokine-induced chronic inflammation in the vessel wall. Current therapeutics effective in preventing atherosclerosis and stroke.
such as statins, acetylsalicylic acid and renin-angiotensin system inhibitors may also exert part of their effects by modulating inflammatory responses in the vessel wall.

**Inflammation in the pathogenic intersection between atherosclerosis and cancer**

Atherosclerosis and cancer are the most important source of morbidity and mortality in the developed world. Both chronic diseases appear to be multi-staged in their progression, with genetic, nutritional, psycho-social, environmental and viral factors influencing their appearances. However, major molecular inflammatory pathways and their nuclear transcription factors, such as NFκB, have a significant role in the pathogenesis and progression of both atherosclerosis and cancer. For example, alteration of cytokine-dependent cell adhesion molecules, such as integrins and cadherins, have been linked to plaque formation and thrombosis, as well as to cancer invasion and metastasis. Altered expression of proteases associated with thrombolysis has also been implicated in atherosclerotic plaque expansion and hemorrhage, and in the pathogenic process of cancer invasion and metastasis. Ligand-growth factor receptor interactions (tyrosine kinases) have been associated with early atherosclerotic lesions, as well as with cancer development and spread. Moreover, pro-angiogenic inflammatory factors have recently been linked to plaque expansion and restenosis of atherosclerotic lesions as well as cancer cell spread from primary tumors and metastatic tumor growth. On this basis, as we move forward in our understanding of these diseases, efforts are increasingly focused on the inflammatory mechanisms underlying disease activation, that precipitate major clinical manifestations of both atherosclerosis—heart attack and stroke—, and cancer, —primary tumor invasion and distant metastasis—. Moreover, novel target-oriented therapies affecting altered mechanisms of inflammation, angiogenesis, matrix remodeling and tissue proliferation have similarly inhibited atherosclerosis and cancer. Main treatment strategies in clinical development include reducing oxidative stress; inhibiting chemokine, cytokine, and growth factor cell signal transmit; down-regulating excess matrix digestion; inactivating nuclear factor-kappa B signal pathway, and interfering cell cycle regulation.

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