

Immunological and Inflammatory Aspects of Periodontal Disease

Michael P. Mills, DMD, MS

Continuing Education Units: 4 hours

This continuing education course is designed for general dentists, dental hygienists, dental students and dental hygiene students. The course reviews key components of the immune system and their coordinated roles in preventing and eliminating the etiologic agents of disease. Current concepts in the immunopathogenesis of periodontal disease will be discussed with emphasis on the role of inflammation in periodontal tissue destruction.

Conflict of Interest Disclosure Statement

The author reports no conflicts of interest associated with this work.

ADA CERP

The Procter & Gamble Company is an ADA CERP Recognized Provider.

ADA CERP is a service of the American Dental Association to assist dental professionals in identifying quality providers of continuing dental education. ADA CERP does not approve or endorse individual courses or instructors, nor does it imply acceptance of credit hours by boards of dentistry.

Concerns or complaints about a CE provider may be directed to the provider or to ADA CERP at:
<http://www.ada.org/prof/ed/ce/cerp/index.asp>



Overview

The module *Immunological and Inflammatory Aspects of Periodontal Disease* reviews key elements of immunity and the role of the immune system in periodontal inflammation. The most current concepts in the progression of the periodontal lesion leading to alveolar bone loss will be discussed.

Learning Objectives

Upon the completion of this course, the dental professional will be able to:

- Define innate and adaptive or acquired immunity.
- Describe principal components of innate and acquired immunity.
- Compare and contrast the five classes of immunoglobulins.
- Name the major types of leukocytes.
- Summarize the four types of hypersensitivity reactions to foreign substances.
- Discuss the origin, maturation, and function of T-cells and B-cells.
- Understand the role of bacterial complexes in periodontal disease.
- Discuss the role of inflammation in periodontal tissue destruction.

Course Contents

- Homeostasis and Immune System
- Language of the Immune System
- Key Elements of Immunity
 - Three Important Characteristics to Adaptive Immunity
 - Immunogens and Antigens
 - Five Classes [subclasses] of Immunoglobulins
 - Blood Leukocytes
 - Granulocytes
 - Monocytes - Macrophages
 - Lymphocytes
 - Maturity of T and B Cells
- Types of Hypersensitivity Reactions
- Progression of the Inflammatory Periodontal Lesion
 - Initial Lesion (2-4 days)
 - Early Lesion (4-7 days)
 - Established Lesion (2-3 weeks)
 - Advanced Lesion
- Osteoimmunology
- Summary
- Course Test
- References
- About the Author



Homeostasis

Homeostasis and Immune System

Periodontal disease pathogenesis is a complex subject, requiring a thorough understanding of the macroscopic and microscopic features of the periodontium (i.e., the supporting structures of the tooth), as well as the role that the immune system plays in the host response.



The human body is continually working to keep the internal environment in a condition of homeostasis. The system that wards off disease and provides resistance to foreign organisms is the immune system. In the oral cavity, plaque microorganisms initiate the gingival lesion by triggering a localized inflammatory reaction. The host immune system choreographs the protective inflammation process and, unfortunately, frequently contributes to the destruction associated with periodontal diseases.

Language of the Immune System

Much progress has been made over the last several decades in unraveling the complex nature of our immune system. The ability of our immune system to protect us is dependent upon the ability of immune cells to communicate with one another in order to coordinate activities. Cells are able to communicate or send signals to each other through either cell-to-cell contact or by secreting

small proteins called cytokines. Cells react to each other or to the cytokines via membrane bound receptors and ligands that are expressed on their surface at the right moment. Ligands are molecules that bind to receptors initiating a signal. Literally hundreds of these receptors and ligands have been identified by immunologists all over the world. Today each receptor is referenced using an international language called the "Cluster of Differentiation" or CD. CD is followed by a number identifying the order in which the receptor was discovered. For example, all T lymphocytes express the receptor CD3. However, a special type of T lymphocyte called a "Helper" T Cell, also expresses the receptor referred to as CD4.

Key Elements of Immunity

Before examining the specifics of oral infections and the host response, several key elements involved in immunity will be summarized. In higher animals, resistance to a pathogen includes a non-adaptive, non-specific or innate response (natural immunity) and an adaptive or acquired response, which act in concert to protect the host. A simple way to remember this is to consider innate immunity as what you are born with. The innate response occurs in the same way and to the same extent regardless of how many times a pathogen is encountered. In contrast, an adaptive or acquired response occurs after a pathogen comes into contact with the host and a "specific response" to that pathogen is developed and stored in a memory bank for any future contact. On second contact with the pathogen, a more rapid and heightened immune response ensues to eliminate it.

Innate immunity includes the following component parts:

- External barriers such as skin, oral mucosa, body secretions and even normal (endogenous) microbial inhabitants
- Physiological factors as body pH and temperature
- Blood and tissue leukocytes (neutrophils, monocytes, macrophages, mast cells, basophils, eosinophils and natural killer cells)
- Dendritic cells for immune surveillance and antigen presentation
- Primary and secondary lymphoid tissue

- Soluble mediators of inflammation including acute phase proteins, complement and cytokines

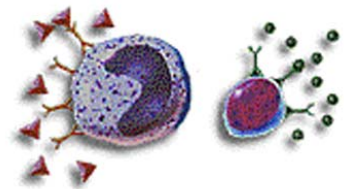
The adaptive or acquired immune response system is mediated by T and B lymphocytes which are commonly referred to as T Cells and B Cells. There are three important characteristics to adaptive immunity:

- Self-recognition (or recognition of non-self)
- Specificity
- Memory

Three Important Characteristics to Adaptive Immunity

Self-Recognition

In healthy, immune competent individuals, immune responses are not produced against "self"-components.



In vertebrates, Major Histocompatibility Complexes (MHC) exist which allow for differentiation between self and non-self antigens. In humans it is called the Human Leukocyte Antigen System (HLA) and it is responsible for genetically encoding our cells for recognition by the Immune System as either self or non-self. Nucleated cells express MHC Class I genes, whereas a subgroup of immune cells called antigen presenting cells (APCs) express MHC Class II genes. In a healthy cell, a MHC Class I molecule coupled with one of the cell's peptides is expressed at the cell surface. This complex acts as a signal to circulating Natural Killer lymphocytes or cytotoxic T cells not to attack. However, if that cell is invaded by a pathogen, the MHC Class I molecule couples to a non-self peptide of the pathogen which then signals the lymphocytes to attack and destroy the cell. Tissue cells that undergo malignant transformation may also express peptides with the MHC Class I molecules that are no longer recognized as self; thus promoting the destruction of cancerous cells.

Specificity

This property refers to the ability of the immune system to recognize non-self antigens and

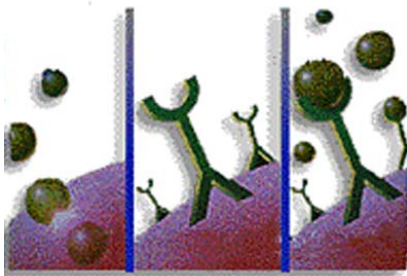


Response to one organism does not give protection against another unrelated organism.

respond in a specific manner to them, rather than responding in a random, general manner. Specificity is initiated by Antigen Presenting Cells such as activated T Cells, B Cells, macrophages, dendritic cells and thymic epithelial cells. The APCs express MHC Class II molecules at their surface which are coupled to antigenic peptides. When this antigenic peptide is presented to a T cell, the T cell becomes activated and in turn helps stimulate B cells to proliferate and differentiate into Plasma Cells which make antibodies "specific" to that antigen only. When the body encounters the measles virus, for example, and responds to it, it does not respond against all other viruses.

Memory

The initial contact with a molecule eliciting an immune response (antigen) leaves an imprint of information. With the help of the activated T cell, B cells also produce memory cells with antigen-specific antibodies expressed on their surface as B cell Receptors. These memory cells live for a



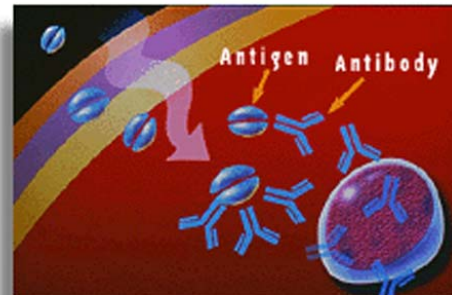
Cells are imprinted with memory from previous contact with antigen. (e.g. infectious agent)

longer period of time and, on second contact with an antigen, can respond more robustly and more quickly to eliminate it. We rarely suffer twice from measles, mumps, etc. The first contact imprints "memory" so that the body repels the next invasion.

Vaccines are synthetic forms or processed natural antigens used to stimulate the production of antibodies. Every time that antigen invades the body, the body remembers (memory), and an appropriate and specific response is produced by the host immune cells and antibodies.

Immunogens and Antigens

Foreign material, including microorganisms, can contain chemical groups recognizable by the body as foreign. In general terms, molecules of any chemical group that elicit an immune response are termed immunogens. More specifically, a molecule that is capable of **generating** an **antibody** is termed an **antigen**. If a microorganism bypasses the body's other defenses, the immune system will produce a specific response that is directed against the particular antigen, or antigens, of this microorganism.

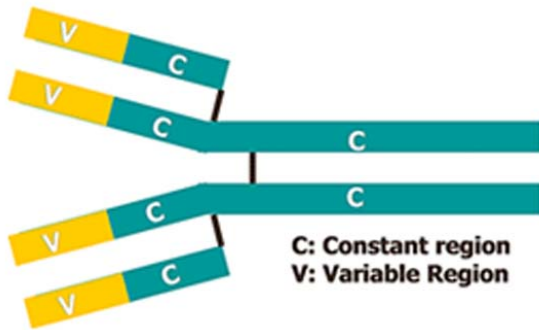


Immunoglobulins

Immunoglobulins (Ig) are gamma globulin proteins present in bodily fluids (e.g. blood serum) and mucosal secretions (e.g., saliva, tears, vaginal secretions), and may also be found at the site of inflammation within the tissue. They are produced by plasma cells, which are differentiated B lymphocytes or B cells. Based on structure and protein composition, immunoglobulins are divided into five classes, two of which are further sub classified. Each has its own distinct chemical structure and specific biological function.

Typical Immunoglobulin Structure

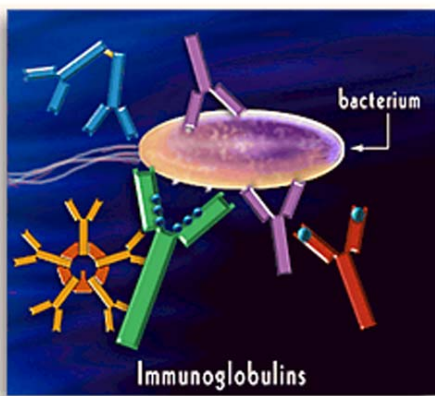
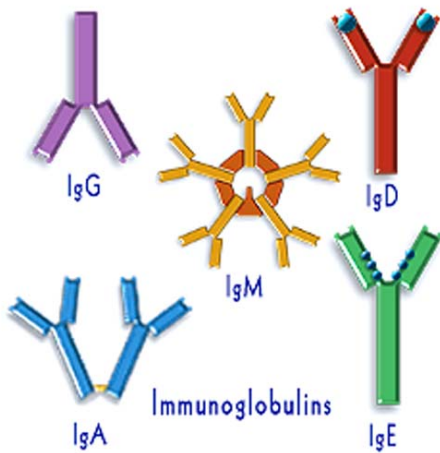
The immunoglobulin molecule is composed of a *Constant* region and *Variable* regions.



The *Constant* region generally is unique to the Ig Class or Ig Subclass and confers its biologic activity. The *Variable* regions form a complex, conformational molecular arrangement for the attachment of each specific antigen.

Five Classes [subclasses] of Immunoglobulins

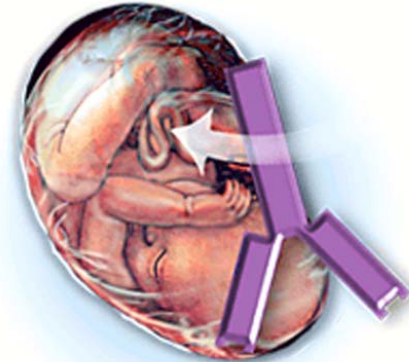
- Immunoglobulin G (IgG) [subclass IgG1, IgG2, IgG3, IgG4]
- Immunoglobulin A (IgA) [subclass IgA1, IgA2]
- Immunoglobulin M (IgM)
- Immunoglobulin D (IgD)
- Immunoglobulin E (IgE)



The five classes [subclasses] of immunoglobulins include:

IgG

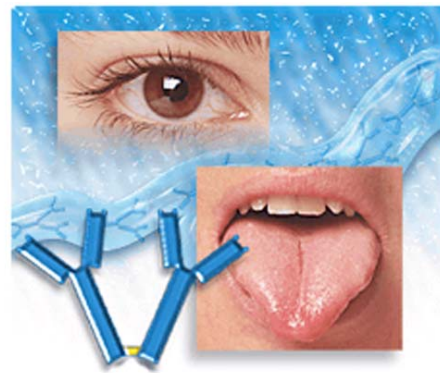
Immunoglobulin G is the main immunoglobulin present in the blood and represents 70% to 75% of the total immunoglobulin pool. Several forms (subclasses) of IgG cross the placental barrier and are responsible for defense against infection in the first few months of a baby's life.



- 70% - 75% of the total pool
- Initial defense in newborns

IgA

Immunoglobulin A provides localized antibody protection on mucosal surfaces. It is found in mucosal secretions such as saliva, tears, sweat, nasal fluids, fluids of the lung and colostrum, genito-urinary tract, and gastro-intestinal tract. It is a primary defense against microorganisms attacking exposed mucosal surfaces. IgA functions by preventing the microorganism from adhering to, and penetrating, the mucosal epithelial lining.



Immunoglobulin A (secretory)

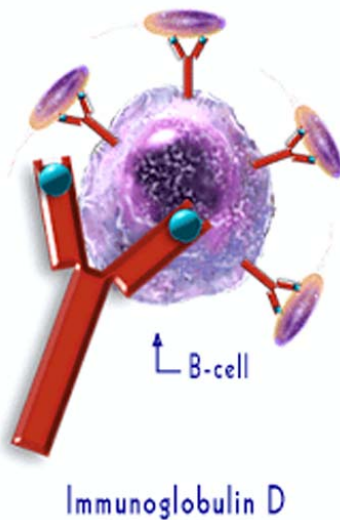
IgM

Immunoglobulin M is the major immunoglobulin present on the surface of immature B cells and is effective against microbes by binding with complement and causing agglutination and bacteriolysis. It is the first immunoglobulin to take part in the immune response and plays an important role in controlling bacteria that find their way into the blood stream (bacteremia).



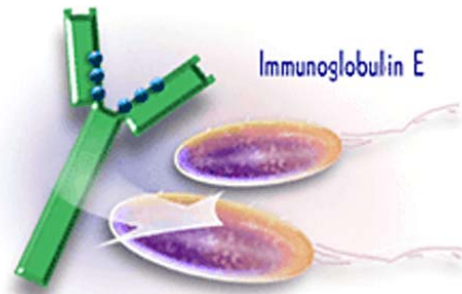
IgD

Immunoglobulin D is a trace antibody in the serum and is present on the surface of B cells. It may be involved in stimulating and suppressing these antibody producing cells in the manufacture of antibodies.



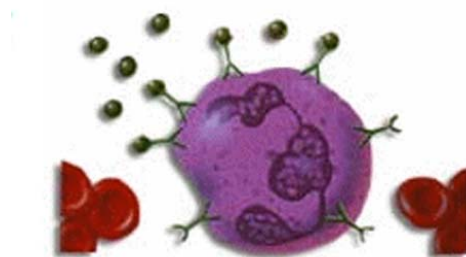
IgE

Immunoglobulin E is found in very low concentration in human serum, but it increases during allergic reactions and some parasitic infections. IgE is bound to high affinity membrane



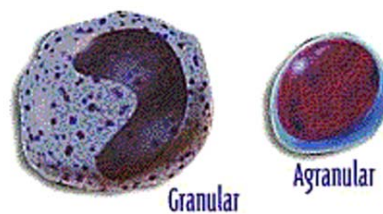
receptors (FcεRI) on mast cells in the tissue and basophils in the blood. Cross-linking of cell bound IgE by an allergen elicits the release of inflammatory mediators like histamine and several cytokines. IgE is also the main immunoglobulin responding to infection caused by certain parasites.

Before we examine how these immunoglobulins function during inflammation and periodontal destruction, let's review the key cellular elements of the immune system, most of which are blood components. When an organism invades the body, the body's initial response is carried out by white blood cells.



Blood Leukocytes

White blood cells, or leukocytes, can be classified into five major categories based on morphological and functional characteristics. They may also be classified as granular or agranular. Leukocytes



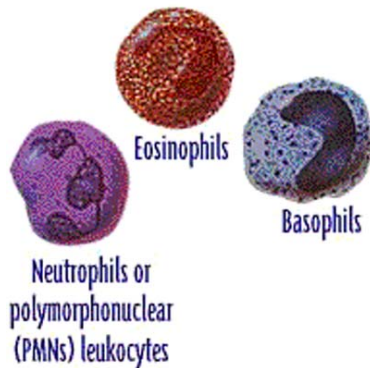
Leukocytes combat microbes by several mechanisms

defend against invading microorganisms either by stimulating specific cellular or humoral (antibody production) immune responses, or by phagocytosis.

There are three types of granular leukocytes (granulocytes):

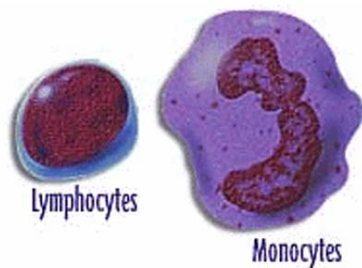
1. Neutrophils or polymorphonuclear leukocytes (PMNs)
2. Eosinophils
3. Basophils

Their names reflect the staining characteristics of the granules present in their cytoplasm.



Monocytes, the fourth group of leukocytes, have few granules and a typically kidney-shaped nucleus. In tissue, monocytes become macrophages.

The last major group of leukocytes includes the lymphocytes. They are agranular round cells, with a proportionally large nucleus. Lymphocytes are primarily responsible for adaptive or acquired immunity.



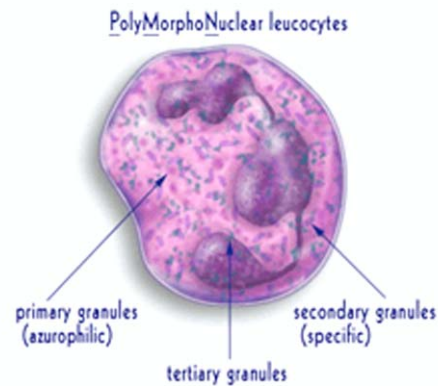
Granulocytes

Neutrophils or PMNs are generally the first cells to migrate to the site of an invading microorganism or the site of trauma. This

directed migration (chemotaxis) is caused by the release of signaling molecules called chemokines which can be released by several different cell types at the site of inflammation. The PMNs eliminate invaders by phagocytosis and other mechanisms. PMNs comprise 50-70% of the circulating leukocytes and more than 90% of the circulating granulocytes.

PMN's have three types of granules:

1. The primary or azurophilic granules are lysosomes that contain powerful digestive enzymes including acid hydrolases, elastase, myeloperoxidase and other proteins such as lysozyme and defensins.
2. Secondary or specific granules contain lactoferrin, lysozyme, collagenase and other proteins.
3. Tertiary granules contain gelatinase and other enzymes.



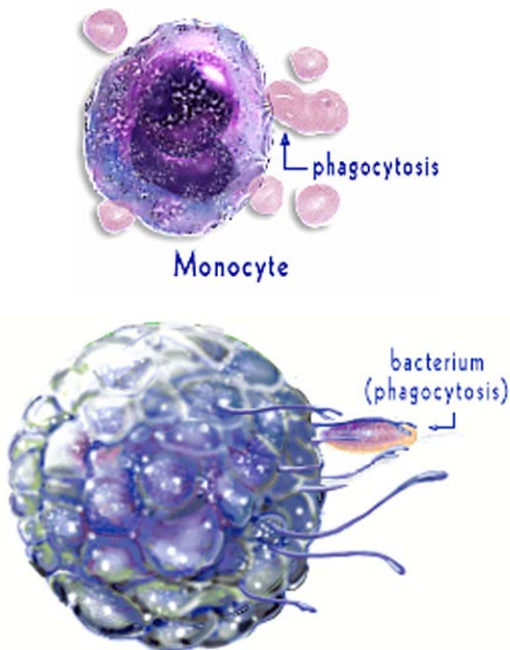
Eosinophils are involved in defense against parasitic infections and in control of allergic (hypersensitivity) reactions. Eosinophils comprise 1% to 3% of blood leukocytes.

Circulating basophils comprise less than 1% of leukocytes. Granules in basophils contain heparin, histamine, and serotonin. When these (and other) chemicals are released from the cell, they cause an acute inflammatory response, which is why they are collectively called mediators of inflammation. Basophils are related to mast cells, which are not found in the circulation. Mast cells and basophils are the cells involved in immediate hypersensitivity reactions (anaphylaxis).

Monocytes - Macrophages

Monocytes, which constitute 3-7% of leukocytes, are usually the second cell type to move to the site of injury or inflammation. Monocytes, like PMNs, can eliminate pathogens and debris by phagocytosis. After leaving the circulation, monocytes develop into tissue macrophages.

Macrophages are active against infectious agents by phagocytosis. They are also antigen presenting cells that take up antigen and, after processing, present the antigen to lymphocytes. Thus, macrophages can help orchestrate the immune response.



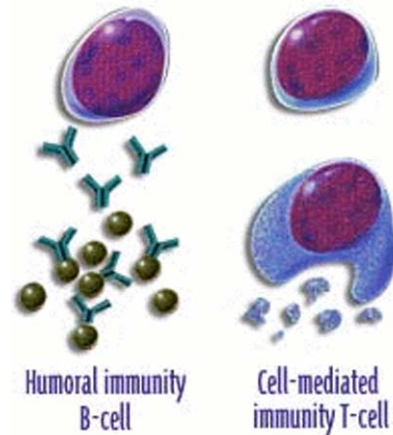
Lymphocytes

Lymphocytes comprise about 30% of the circulating leukocytes. Lymphocytes are involved in the development of adaptive or acquired immune responses. There are two major types of lymphocytes: T-cells and B-cells, both having surface receptors for antigen.

The Antigen-Antibody Reaction

When an antigen enters the body, two types of adaptive immune responses can occur:

- The synthesis and release of free antibody into the blood and other body fluids, called Humoral Immunity, is provided by B-cells.

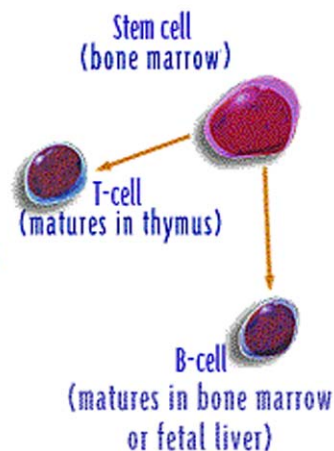


- The production of sensitized lymphocytes called T-cells that are effectors of Cell-mediated Immunity.

Cellular Immunity involving T-cells is effective against fungi, many parasites, intracellular bacteria, most viruses, cancer cells, and surgically transplanted or transfused foreign tissues. This is the type of response associated with graft rejection in transplant cases, and also with transfusion incompatibility.

Humoral Immunity, through circulating antibodies, is effective against extracellular organisms, including bacteria, some parasites, and some viruses.

Lymphocytes are produced in bone marrow from stem cells. A portion of the lymphocytic precursor cell population migrates to the thymus to mature into T-cells, while others are



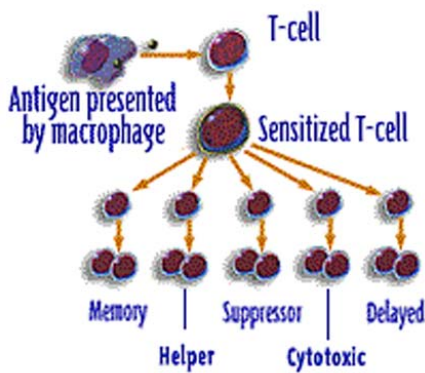
processed in the bone marrow to become B-cells. It should be mentioned that at 8-9 weeks of fetal development, B cells form in the liver but, soon after, the bone marrow becomes the primary site of production. The thymus gland and bone marrow are considered primary lymphoid organs while peripheral lymph nodes, mucous associated lymphoid tissue and the spleen are considered secondary lymphoid organs.

Maturity of T and B Cells

The T Cell: T-cells mature in the thymus gland or in the lymph nodes. Since the thymus is only 10-15% functional in the adult, the lymph nodes take on greater importance in the maturation process.

Thymus Gland: T Cells migrating to the Thymus gland from the bone marrow will undergo a process of selection to eliminate not only the weakest cells, but also those so strong that they may attack healthy tissue cells (autoimmunity). Cells educated in the Thymus generally are either Helper (CD4+) or Suppressor/Cytotoxic (CD8+) cells.

Lymph Node: Naive T cells in the paracortex of the lymph node may be activated by dendritic cells that have internalized and processed pathogenic antigens that made their way to the lymph node via lymphatic drainage from the site of infection or inflammation. Once activated, T cells undergo clonal expansion and differentiate into functional effector cells (short-lived) or memory effector cells (long-lived). Functional effector cells migrate to the site of infection or inflammation where they orchestrate T helper (CD4+) or T cytotoxic/suppressor (CD8+) functions to combat pathogens. Memory cells may enter the



circulation or healthy tissue sites, or remain in the lymph node.

The B Cell: B cells mature in the bone marrow or in the lymph node.

Bone Marrow: Mature B cells express antibodies on their surface that are specific for a particular antigen. The antibodies expressed are primarily IgM with some IgD. These cells circulate in the blood or home to sites of infection or inflammation. However, until they are activated, they do not proliferate or differentiate to form antibody producing Plasma Cells.

Lymph Node: Antigen-dependent B cells in the cortex of the lymph node may be stimulated by Helper T cells to proliferate and differentiate into Plasma Cells and memory cells. Immunoglobulin (antibody) class switching of the B cell from IgM to IgG or IgA or IgE may also take place as a result of the T cell interaction.

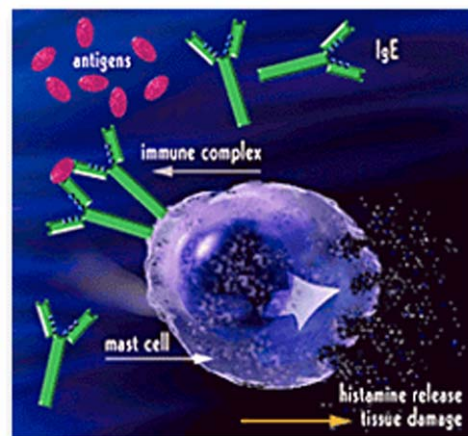
Types of Hypersensitivity Reactions

The response of the host to the presence of foreign substances can trigger four types of hypersensitivity reactions:

1. Immediate
2. Cytotoxic
3. Immune complex
4. Cell-mediated

Type I: Immediate Hypersensitivity (Anaphylactic Reaction)

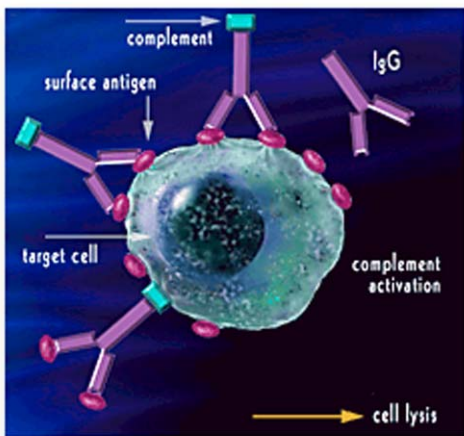
These allergic reactions are systemic or localized, as in allergic dermatitis (e.g. hives, wheal and



erythema reactions). It is a reaction of an antigen with IgE antibody bound to a mast cell or basophil. Histamine, serotonin, bradykinin, and lipid mediators (e.g. platelet activating factor, prostaglandins, and leukotrienes) are released during the anaphylactic reaction. These released substances have the potential to cause tissue damage.

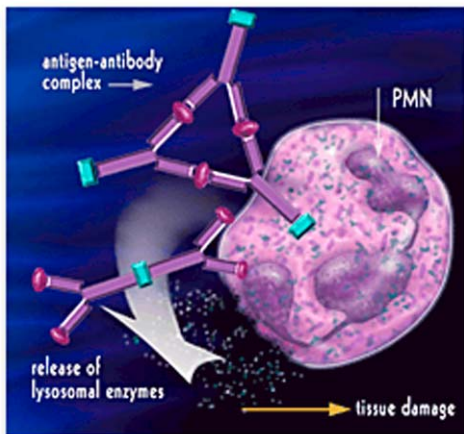
Type II: Cytotoxic Reaction (Antibody-dependent)

In a cytotoxic reaction, the antibody reacts directly with the antigen to induce cell lysis through complement activation. Cytotoxic reactions are mediated by IgG and IgM. Examples of cytotoxic reaction are the Rh incompatibility of a newborn, blood transfusion reactions, and autoimmune diseases like Goodpasture's syndrome.



Type III: Immune Complex Reaction

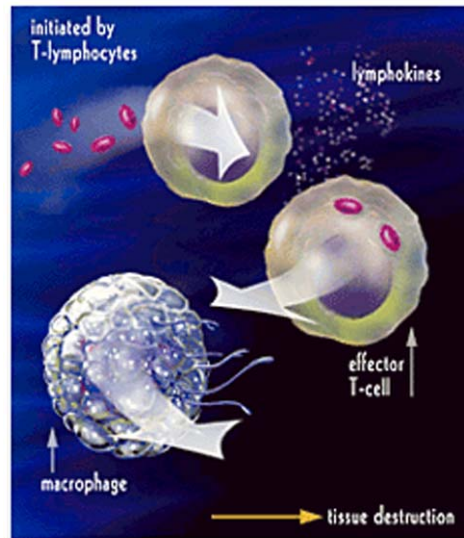
IgG and IgM bind antigen, forming antigen-antibody (immune) complexes. These activate complement, which results in PMN chemotaxis and activation. PMNs then release tissue



damaging enzymes. Tissue damage present in autoimmune diseases (e.g. systemic lupus erythematosus), and chronic infectious diseases (e.g. leprosy) can be attributed, in part, to immune complex reactions.

Type IV: Cell-Mediated (Delayed Hypersensitivity)

Cell-mediated reactions are initiated by T-lymphocytes and mediated by effector T-cells and macrophages. This response involves the interaction of antigens with the surface of lymphocytes. Sensitized lymphocytes can produce cytokines, which are biologically active substances that affect the functions of other cells. This type of reaction takes 48-72 hours, or longer, after contact with the antigen to fully develop. Many chronic infectious diseases, including tuberculosis and fungal infections, exhibit delayed hypersensitivity.



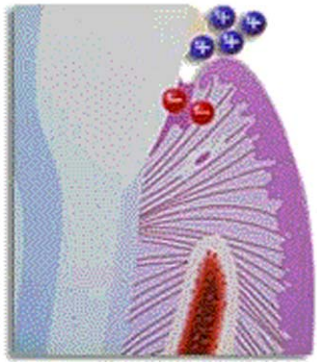
Evidence suggests that hypersensitivity reactions, particularly Type III and IV, may be involved in the pathogenesis of periodontal disease.

Progression of the Inflammatory Periodontal Lesion

As with most infections, the inflammatory reaction within the gingival tissue serves to contain or stop a local microbial attack, and prevents the spread of attacking organism. However, a robust inflammatory reaction may also result in the destruction of surrounding cells, connective tissue matrix and eventually bone. The progression from relative health to advanced disease is best explained by reviewing the mechanisms of

plaque induced inflammation and the immune components involved in initiating and propagating the inflammatory process.

Early visible inflammatory changes in the gingival margin occur within a few days if plaque growth is undisturbed. Within 10 to 20 days the plaque mass changes composition from mostly gram-positive coccoid and filamentous bacteria to gram-negative rods and spirochetes. A gram-positive plaque is usually associated with periodontal health, while a gram-negative is associated with disease. This complex community of microorganisms is referred to as a biofilm.



Early supragingival plaque is a colonization of gram-positive organisms

Gram-negative and gram-positive microorganisms within the biofilm produce and release a variety of metabolic by-products that are toxic to host tissues. These include exotoxins, endotoxins, odor-producing metabolites (e.g. hydrogen sulfide) and many different tissue-degrading enzymes, including bacterial collagenase and various proteases.

Several of the more common periodontal pathogenic bacteria have been grouped into complexes based on their association with the periodontal lesion. The most virulent of organisms form the Red Complex and consists of *Porphyromonas gingivalis*, *Tannerella forsythia*, and *Treponema denticola*. The Orange complex is composed of *Prevotella intermedia*, *Prevotella nigrescens*, *Peptostreptococcus micros*, *Eubacterium nodatum*, *Streptococcus constellatus*, three *Campylobacter* species including *Campylobacter rectus*, and 4 species of *Fusobacterium*. These two complexes of periodontal pathogens become more prevalent in

numbers and occurrence as the periodontal pocket deepens. *Aggregatibacter actinomycetemcomitans* serotype b, which is strongly associated with aggressive forms of periodontitis, appears to be an "outlier" (i.e. not placed into any grouping or complex, but very virulent just the same).

Other groups of periodontal biofilm bacteria that form the Blue, Yellow, Green and Purple Complexes primarily consist of tooth surface colonizers including *Streptococcus*, *Actinomyces* and *Capnocytophaga* species. The Red and Orange Complex bacteria, on the other hand, mostly colonize nearer to epithelial surfaces of the pocket wall. Of the most virulent organisms, *Porphyromonas gingivalis*, *Tannerella forsythia*, *Aggregatibacter actinomycetemcomitans*, *Treponema denticola*, *Prevotella intermedia*, *Fusobacterium nucleatum*, and *Eikenella corrodens* have also been shown to invade epithelial cells. This is a characteristic that allows the microorganism to evade the immune system.

Not all plaque-induced inflammatory lesions progress from gingivitis to periodontitis. A healthy immune response will protect the host by eliminating the noxious stimuli through coordinated response of the innate and acquired immune system. Lesions that do progress are the result of a heightened inflammatory response in a susceptible host. This response may be related to a variety of factors including: 1) the type and virulence of the bacterial plaque; 2) host immune defects that are genetically determined or acquired, such as in AIDS; 3) decreased immune function resulting from medically related conditions (e.g. diabetes, leukemia and autoimmune diseases); 4) social habits such as drug and alcohol abuse and smoking; and 5) environmental factors such as stress and exposure to toxins.

In order to better understand the complex role of the innate and acquired immune system in the initiation and progression of periodontal disease, models of disease will be presented that utilize the four stages in the pathogenesis of inflammatory periodontal disease originally described by Page and Schroeder, Laboratory Investigation, 1976.

Initial Lesion (2-4 days)

If a biofilm is allowed to form on the tooth surface, a vast number of bacterial cell products are produced. Many of these bacterial products

and structures are referred to as Pathogen-Associated Molecular Patterns (PAMPs) and can be recognized by membrane receptors called Toll-like Receptors (TLRs). TLRs are part of the innate immune system and are expressed by several different cell types including Epithelial cells, endothelial cells, fibroblasts, cementoblasts, osteoblasts, osteoclasts, dendritic cells, PMNs, macrophages and lymphocytes.

When PAMPs (Table 1) bind to TLRs on the cell membrane, an immune response is launched. The result is an inflammatory response that is initiated by the release of pro-inflammatory molecules, called cytokines, and other soluble

mediators of inflammation from the cell. The major pro-inflammatory cytokine is Interleukin-1 (Il-1 α , Il-1 β , Il-1Ra), which is released by several different cell types including sulcular/junctional epithelium, fibroblasts, macrophages and PMNs. The functions of Il-1 are listed in Table 2.

The release of Il-1 initiates a series of events that are usually associated with an acute inflammatory phase. Most of the events described below occur in an orchestrated manner to eliminate the pathogens.

- Chemotactic cytokines or chemokines, such as Il-8, will be released which attract circulating PMNs; “the first line of defense.”

Table 1. Pathogen Associated Molecular Patterns
<ul style="list-style-type: none"> • Lipopolysaccharide (LPS): g (-) cell wall • Peptidoglycan: g (+) cell wall, some g (-) cell walls • Lipoteichoic acids: g (+) cell wall • Mannose: microbial CHO - • Flagellin: bacterial flagella • Pilin: bacterial pili • Bacterial nucleic acids • Viral RNA • Yeast cell walls: lipoteichoic acids, glycolipids, zymosan

Table 2. Functions of Interleukin-1
<ul style="list-style-type: none"> • Up-regulates complement and Fc receptors on neutrophils and monocytes • Up-regulates adhesion molecules on fibroblasts and leukocytes • Up-regulates adhesion molecules on endothelial cells • Induces homing receptors for lymphoid cells in the extracellular matrix • Induces osteoclast formation and bone resorption (RANKL) • Stimulates MMP and prostaglandin production by macrophages, PMNs and fibroblasts • Up-regulates MHC expression by B and T cells for activation, clonal expansion and immunoglobulin production • Induces interleukins 2, 3, 4, 5, 6, 7, 8, 10, 12, & TNF-α

- PMNs then migrate through the vascular wall (diapedesis) and follow a concentration gradient of chemical molecules (chemotaxis) to the site of infection.
- PMNs not only release enzymes that are capable of destroying pathogens but also attach to antigen-antibody complexes for phagocytosis. PMNs will also migrate between junctional epithelial cells to reach the sulcus, where they literally burst and release their enzymes.
- Histamine and kinins released from tissue Mast cells promote vasodilation and increase vascular permeability, enhancing the influx of cells and protein molecules such as antibodies and complement.
- Plasma proteins called Complement will be activated through a cascade of enzymatic reactions. There are three pathways for the activation of complement: The Classical; Alternative; and Mannose-binding lectin.
- Complement has several biologic functions
 - C3a activates basophils and mast cells causing release of vasoactive substances including histamine.
 - In concert with antibodies, C3b and C4b opsonize, or clump, the antigens together for easier phagocytosis by PMNs and macrophages
 - C5a and C5a des Arginine enhance PMN activation and chemotaxis
 - C5b, C6, C7, C8 form a Membrane Attack Complex (MAC) that can destroy bacteria by punching holes in their cell wall.
- The antibodies entering the tissue come from the circulation. Some may be specific for certain pathogen-associated antigens and come from the IgG and IgA classes and subclasses. Others that are less specific or of weaker affinity will be of the IgM class.
- PMNs and gingival fibroblasts may release enzymes called matrix metalloproteinases, or

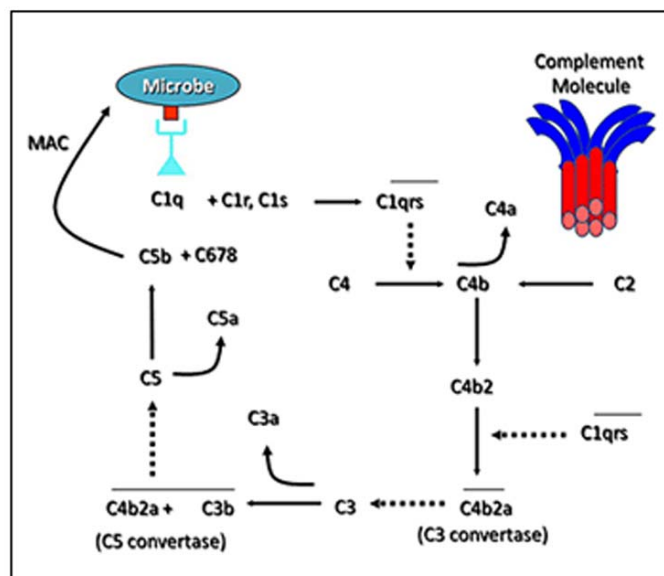
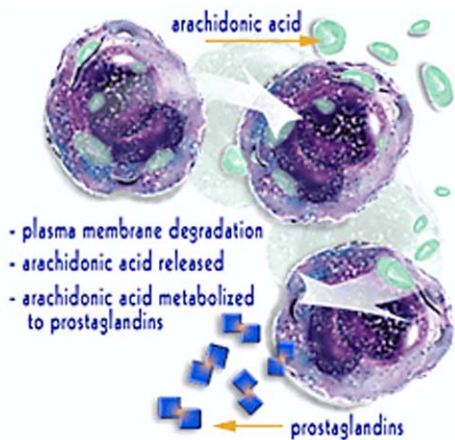


Table 3. Matrix Metalloproteinase (MMP)

- MMP (Zn⁺⁺) enzymes digest extracellular matrix
- MMP-1, 8, 13: Collagenases (FØ, PMN)
- MMP-2, 9: Gellatinases
- MMP-3, 10, 11: Stromylysins
- MMP-7: Matrilysins
- Membrane anchored MMPs: 14, 15, 16, 17, 24, 25

MMPs (Table 3). These include collagenase and elastase that are capable of breaking down extracellular matrix like collagen fibers.

In addition, several cell types will be induced by Il-1 to produce Prostaglandin (PG), a by-product of the enzymatic breakdown of arachidonic acid found in the lipid layer of the cell membrane. All nucleated cells except lymphocytes produce PG. The prostaglandin of significance in periodontal disease is PGE2. It has been demonstrated to increase in concentration as the severity of the lesion increases. PG functions include platelet aggregation, vasodilation, vasoconstriction, chemotaxis of PMNs, increased vascularity and bone resorption.



Clinically, the manifestation of these events results in the early stages of gingivitis. There may be bleeding on probing, slight gingival swelling along with mild erythema (reddening) of the tissue, and increased flow of gingival crevicular fluid. Microscopically, the inflammatory infiltrate is predominated by PMNs located primarily around vessels within the connective tissue, just below the junctional epithelium (JE). Loss of some perivascular collagen will also be seen. Within the sulcular epithelium, the number of dendritic cells called Langerhan's cells will increase. These cells can internalize pathogen-associated antigens and migrate, via lymphatic channels, to the lymph node where they become Antigen Presenting Cells (APCs). Free antigen may also travel to the lymph node, where macrophages or specialized dendritic cells internalize, process and present the antigen to T Cells.

If the immune response is effective in eliminating the pathogens in the early phase of the acute inflammation, lipoxins from the enzymatic breakdown of arachidonic acid are generated. The lipoxins may act to inhibit PMN chemotaxis, inhibit secretion of proinflammatory mediators, induce apoptosis (cell death) of PMNs, and, recruit macrophages to the site for removal of cell debris. Thus, the inflammation resolves and tissue repairs. Other molecular compounds, called Resolvins and Protectins, are produced from the metabolism of dietary Omega 3, and act in a similar fashion to the lipoxins.

Early Lesion (4-7 days)

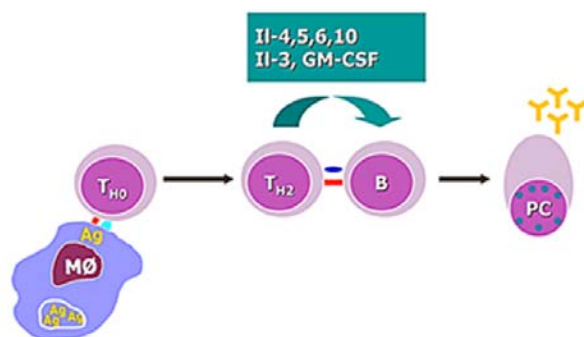
If the pathogens have not been eliminated, the immune response will intensify. Hallmarks of the *Initial Lesion* will continue, but will be accentuated. Clinically, there may be more swelling (edema) along with increased redness (erythema). Microscopically, the area of inflammatory infiltrate will increase, occupying as much as 10-15% of the gingival connective tissue beneath the junctional and sulcular epithelium. Loss of extracellular collagen may be as great as 60-70%, with cytopathic changes seen in the gingival fibroblasts. In an attempt to wall-off the growing lesion, JE cells will begin to proliferate in numbers.

Although PMNs are still prominent in number, lymphoid cells can now be seen accumulating subjacent to the junctional epithelium. Many of the lymphocytes come directly from the circulating blood responding to specialized chemokines that signal them to home to the site of the lesion. Other lymphocytes will begin to arrive from surrounding lymphoid tissue. Several studies have shown these small lymphocytes to be primarily T cells. Once activated by Antigen Presenting Cells such as the macrophage or dendritic cell, T Cells may function as helper and / or cytotoxic cells that orchestrate an appropriate immune response. This is accomplished through the production of various cytokines, or by cell-to-cell interaction. In a gingivitis lesion, T helper Cells increase the ability of macrophages to kill intracellular and extracellular pathogens, activate PMNs independently of the cytokines produced, and enhance PMN and macrophage phagocytosis. This is probably why T Cells are linked to the "stable lesion" as in gingivitis, since they tend to keep the infection under control.

Established Lesion (2-3 weeks)

If the T Cell is unable to effectively deal with the infection and it becomes chronic, a more robust immune response may be required. There is, however, a persistence of the manifestations of acute inflammation. The inflammatory infiltrate in the *Established Lesion* occupies a greater area within the connective tissue, with more destruction of collagen matrix. Again, the junctional epithelium will attempt to occupy the space and wall-off the infection by migrating laterally and apically, resulting in early pocket formation. Another significant change from earlier stages of disease is the predominance of Ig producing Plasma Cells within the inflammatory infiltrate. Thus, an increase in extravascular immunoglobulins (antibodies) can now be detected within the connective tissue and junctional epithelium. These changes may be linked to one or more immune system events.

- It is logical that B Cells have migrated to the site of infection in the *Established Lesion*. Some are memory B cells that have antigen-specific Immunoglobulins (Ig) expressed on their surface membrane. Macrophage-activated T helper-2 Cells (Th2), with receptors for the same specific antigen, will link to the B Cell and activate it. The process of activation results in proliferation and differentiation into Ig producing Plasma Cells. Immunoglobulins will subsequently be available to opsonize and neutralize the antigens. Cytokines Il-3, Il-4, Il-5, Il-6, Il-10 and granulocyte-monocyte colony stimulating factors (GM-CSF), released by the T Cell, are important signaling molecules for proliferation and differentiation of B Cells.



- Other B Cells that express IgM antigen receptors may be activated independently of T Cell help. These B Cells respond to

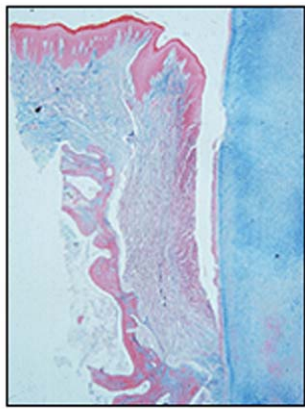
T-independent antigens, many of which are large bacterial carbohydrates that cross-link the IgM antibodies. In a similar manner, macrophages may also present multiples of the same antigen to B Cells for cross-linking of IgM.

Advanced Lesion

Several of the features described for the *Established Lesion* will persist at this stage. Plasma Cells continue to be the predominant cell type within the inflammatory infiltrate. Further destruction of collagen subjacent to the junctional epithelium is seen, with fibrosis at distant sites. A prime characteristic of the *Advanced Lesion* is the extension of the lesion into the periodontal ligament and supporting bone. The resulting outcome is bone loss that is exhibited as clinical attachment loss and pocket formation. The mediators of inflammation that have been identified as playing a significant role in alveolar bone resorption include interleukin-1 β , interleukin-6, Tumor Necrosis Factor- α (TNF α), and Prostaglandin E2. Every cell involved in the immune response is capable of secreting these molecules. In addition, each of these mediators has been shown to increase in periodontitis sites compared to sites displaying gingivitis or health. The newest area of investigation involves the Receptor Activator of Nuclear Factor κ B Ligand, (RANKL) and its decoy receptor, osteoprotegerin. The role of RANKL will be discussed in the following section on *Osteoimmunology*.

Osteoimmunology

"Osteoimmunology" is one of the newest areas of scientific investigation. The term *oste-immunology* specifically refers to the study of the regulation of osteoclastogenesis through the Receptor Activator of Nuclear Factor κ B Ligand (RANKL). RANKL has been described as the "master switch regulator" of osteoclastogenesis. Since bone homeostasis is a balance between bone formation (osteoblastogenesis) and bone resorption (osteoclastogenesis), understanding the regulatory mechanisms between these phases may provide greater insight into bone diseases where the scale is tipped in favor of resorption. Since periodontitis is an inflammatory disease characterized by alveolar bone loss, controlling the expression of RANKL in the periodontal lesion may be a useful treatment approach.



Periodontal Vertical Bony Defect

Osteoblasts express RANKL on their cell membrane. When this ligand binds to the RANKL receptor on a pre-osteoclast, it signals the cell to differentiate into an active osteoclast. The decoy receptor for RANKL, called osteoprotegerin, blocks this activation mechanism, thus helping to maintain bone homeostasis. In periodontitis, the ratio of RANKL to osteoprotegerin increases, whereas in health, the ratio is decreased. This ratio appears to be more important in identifying bone resorbing sites than the concentration of either RANKL or osteoprotegerin alone. What is known about RANKL and the periodontal lesion?

- Osteoblasts and periodontal ligament fibroblasts express RANKL on their cell membrane. T Cells not only express membrane bound RANKL, but also secrete it in soluble form. The pro-inflammatory cytokines interleukin-1 β and interleukin-6, Tumor Necrosis Factor- α and the eicosanoid Prostaglandin E2 signal these cells to express

membrane-bound RANKL, and the T Cell to secrete RANKL. Recall that these molecules have already been shown to be increased in the periodontal lesion and indirectly involved in periodontal bone loss. Thus, when the lesion has advanced toward the periodontal ligament and alveolar bone, the up-regulation of RANKL may lead to bone loss and subsequent deepening of the periodontal pocket.

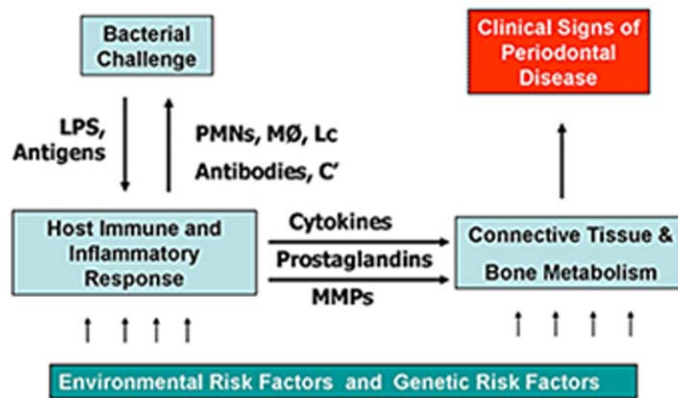
- Gingival fibroblasts produce osteoprotegerin, which may help prevent bone resorption in the earlier stages of periodontal disease where the lesion is primarily confined to an area beneath the epithelium.

Summary

The immune system is a complex array of cells and molecules operating in an orchestrated manner in order to protect the host from pathogenic microorganisms and exogenous noxious agents within our environment. However, destruction of host tissue may occur if the immune response is inadequate due to intrinsic or extrinsic mechanisms in cell function, or if there is a hyper-responsiveness due to dysfunctional regulatory mechanisms. The pathogenesis of periodontal disease is clearly of an inflammatory origin and, as such, has a close association with the Immune System. Unraveling the intricate mechanism by which the host responds to pathogens colonizing the tooth will lead to more sensitive means to detect subtle changes in disease activity, and more effective and predictable therapeutic modalities. The figure below is a simplified model reminding us of the complex nature of periodontal disease.

Pathogenesis of Periodontitis

Page RC et al. *Ann Periodontol* 1998



To receive Continuing Education credit for this course, you must complete the online test. Please go to www.dentalcare.com and find this course in the Continuing Education section.

Course Test Preview

1. **Protective mechanisms such as external barriers and bodily secretions are components of:**
 - a. Innate immunity
 - b. Adaptive immunity

2. **The key cells involved in developing adaptive or acquired immunity are:**
 - a. Neutrophils
 - b. Macrophages
 - c. T & B lymphocytes

3. **The immunologic principle involved with the ability of a vaccine to prevent disease is:**
 - a. Self-recognition
 - b. Memory
 - c. Specificity

4. **The immunoglobulin responsible for defense against infection during the first few weeks of life is:**
 - a. IgG
 - b. IgA
 - c. IgM
 - d. IgD
 - e. IgE

5. **The first immunoglobulin to respond to an infection is:**
 - a. IgA
 - b. IgM
 - c. IgD
 - d. IgE

6. **The immunoglobulin involved in allergic reactions is:**
 - a. IgG
 - b. IgA
 - c. IgM
 - d. IgD
 - e. IgE

7. **The migration of neutrophils, or polymorphonuclear leukocytes (PMNs), to the site of an invading microbe is referred to as:**
 - a. Gradient migration
 - b. Diapedesis
 - c. Chemokinesis
 - d. Chemotaxis

8. **Heparin, histamine and serotonin, which intensify inflammation are released by:**
 - a. Basophils
 - b. Eosinophils
 - c. Lymphocytes
 - d. Dendritic cells

9. **Lymphocytes that are effectors of cell-mediated immunity are called:**
 - a. T-Cells
 - b. B-cells

10. **T-cells mature in which of the following organs?**
 - a. Spleen
 - b. Liver
 - c. Thymus gland
 - d. Bone marrow

11. **Immune complex reactions are categorized into which type of immune hypersensitivity?**
 - a. Type I
 - b. Type II
 - c. Type III
 - d. Type IV

12. **The composition of undisturbed plaque changes from gram-positive coccoid and filamentous bacteria to gram-negative rods and spirochetes.**
 - a. True
 - b. False

13. **The bacterial pathogens most often associated with destructive periodontitis make up the:**
 - a. Red complex
 - b. Orange complex
 - c. Blue complex
 - d. Green complex

14. **The primary pro-inflammatory cytokine is:**
 - a. Prostaglandin E2
 - b. Tumor Necrosis Factor
 - c. Interleukin-1
 - d. Interleukin-6

15. **The T-cell predominates in which stage of periodontal disease:**
 - a. Initial
 - b. Early
 - c. Established
 - d. Advanced

References

1. Delves PJ, Roitt IM. The immune system. First of two parts. *N Engl J Med*. 2000 Jul 6;343(1):37-49.
2. Delves PJ, Roitt IM. The immune system. Second of two parts. *N Engl J Med*. 2000 Jul 13;343(2):108-17.
3. Medzhitov R, Janeway C Jr. Innate immunity. *N Engl J Med*. 2000 Aug 3;343(5):338-44.
4. Klein J, Sato A. The HLA system. First of two parts. *N Engl J Med*. 2000 Sep 7;343(10):702-9.
5. von Andrian UH, Mackay CR. T-cell function and migration. Two sides of the same coin. *N Engl J Med*. 2000 Oct 5;343(14):1020-34.
6. Kamradt T, Mitchison NA. Tolerance and autoimmunity. *N Engl J Med*. 2001 Mar 1;344(9):655-64.
7. Walport MJ. Complement. First of two parts. *N Engl J Med*. 2001 Apr 5;344(14):1058-66.
8. Walport MJ. Complement. Second of two parts. *N Engl J Med*. 2001 Apr 12;344(15):1140-4.
9. Socransky SS, Haffajee AD. Periodontal microbial ecology. *Periodontol 2000*. 2005;38:135-87.
10. Holt SC, Ebersole JL. *Porphyromonas gingivalis*, *Treponema denticola*, and *Tannerella forsythia*: the "red complex", a prototype polybacterial pathogenic consortium in periodontitis. *Periodontol 2000*. 2005;38:72-122.
11. Sandros J, Papanou PN, Nannmark U, Dahl G. *Porphyromonas gingivalis* invades human pocket epithelium in vitro. *J Periodontal Res*. 1994 Jan;29(1):62-9.
12. Page RC, Schroeder HE. Pathogenesis of inflammatory periodontal disease. A summary of current work. *Lab Invest*. 1976 Mar;34(3):235-49.
13. Kornman KS, Page RC, Tonetti MS. The host response to the microbial challenge in periodontitis: assembling the players. *Periodontol 2000*. 1997 Jun;14:33-53.
14. Dennison DK, Van Dyke TE. The acute inflammatory response and the role of phagocytic cells in periodontal health and disease. *Periodontol 2000*. 1997 Jun;14:54-78.
15. Gemmell E, Marshall RI, Seymour GJ. Cytokines and prostaglandins in immune homeostasis and tissue destruction in periodontal disease. *Periodontol 2000*. 1997 Jun;14:112-43.
16. Cochran DL. Inflammation and bone loss in periodontal disease. *J Periodontol*. 2008 Aug;79(8 Suppl):1569-76.
17. Offenbacher S, Barros SP, Beck JD. Rethinking periodontal inflammation. *J Periodontol*. 2008 Aug;79(8 Suppl):1577-84.
18. Graves D. Cytokines that promote periodontal tissue destruction. *J Periodontol*. 2008 Aug;79(8 Suppl):1585-91.
19. Reynolds JJ, Meikle MC. Mechanisms of connective tissue matrix destruction in periodontitis. *Periodontol 2000*. 1997 Jun;14:144-57.
20. Noguchi K, Ishikawa I. The roles of cyclooxygenase-2 and prostaglandin E2 in periodontal disease. *Periodontol 2000*. 2007;43:85-101.
21. Mahanonda R, Pichyangkul S. Toll-like receptors and their role in periodontal health and disease. *Periodontol 2000*. 2007;43:41-55.
22. Gemmell E, Yamazaki K, Seymour GJ. The role of T cells in periodontal disease: homeostasis and autoimmunity. *Periodontol 2000*. 2007;43:14-40.
23. Serhan CN. Controlling the resolution of acute inflammation: a new genus of dual anti-inflammatory and proresolving mediators. *J Periodontol*. 2008 Aug;79(8 Suppl):1520-6.
24. Nagasawa T, Kiji M, Yashiro R, Hormdee D, et al. Roles of receptor activator of nuclear factor-kappaB ligand (RANKL) and osteoprotegerin in periodontal health and disease. *Periodontol 2000*. 2007;43:65-84.

About the Author

Michael P. Mills, DMD, MS



Dr. Mills is a Clinical Associate Professor with teaching responsibilities in the Postdoctoral Division of the Department of Periodontics. Prior to joining the faculty at UTHSCSA in 2000, Colonel Mills completed a distinguished 30-year career in the Air Force. Prior to his retirement, he served as the Chairman and Program Director of the United States Air Force Periodontics Residency at Wilford Hall Medical Center. He also held appointments as the Chief Consultant in Periodontics to the USAF Surgeon General and Special Consultant to the USAF Assistant Surgeon General for Dental Services. Dr. Mills received his dental degree from the University of Alabama School of Dentistry in 1970 followed by a one year General Practice Residency at Eglin USAF Regional Hospital in Florida. From 1977 to 1980, he received his specialty training at Wilford Hall Medical Center, Lackland AFB, Texas and completed requirements for the Master of Science degree at the University of Texas Health Science Center, Houston.

Dr. Mills is a Diplomate and former Chairman and Director of the American Board of Periodontology. He is a member of the American Academy of Periodontology, American Board of Periodontology, American Dental Association, Texas Dental Association, Southwest Society of Periodontists, and San Antonio District Dental Society. He has authored or co-authored 30 scientific articles and abstracts and 2 textbook chapters: one on the *Principles and Practice of Periodontal Surgery* and the other on *Osseous Surgery: The Resective Approach*. He also served as a reviewer for the 1996 World Workshop in Periodontics authoring a section on Anxiety and as a section participant on *Periodontal Regeneration* in the 2003 Contemporary Science Workshop. His expertise and interests cover a wide range of clinical periodontics and dental implantology with particular interest in osseous surgery and anatomy. His interest in immunology began in 1977 and has persisted ever since. He has taught immunology to Periodontics Residents for the past 26 years emphasizing the changing concepts in the immunopathogenesis of periodontal disease.

E-mail: MILLSM@uthscsa.edu