

January 2, 2012

- [Home](#)
- [Contact](#)
- [Help](#)
- [Author Services](#)
- [Author Log In](#)
- [Subscriber Services](#)
- [Subscriber Log In](#)
- [Johns Hopkins CME](#)
- [About](#)
- [About the Author](#)



- [Medical Specialties](#)
- [Life Sciences](#)
- [Species and Cell Types](#)
- [Research Technology](#)
- [Therapeutic Technology and Methodology](#)
- [Pharmaceutical and Healthcare Industry](#)
-
-
-

Article Published in the Author Account of

Alison M Hofmann**New Roles for Mast Cells in Pathogen Defense and Allergic Disease**

Published on February 2, 2010

Author: [Alison M Hofmann](#)Specialty: [Immunology](#), [Pediatrics](#)

Institution: Pediatric Allergy and Immunology, Duke University

Address: DUMC 2898, Durham, North Carolina, 27710, United States

Author: [Soman N Abraham](#)Specialty: [Immunology](#), [Microbiology](#), [Infectious Diseases](#)

Institution: Departments of Pathology, Immunology, and Genetics & Molecular Microbiology, Duke University

Address: DUMC 3020, Durham, North Carolina, 27710, United States

Institution: Program in Emerging Infectious Diseases, Duke-National University of Singapore

Address: Singapore, Singapore

Abstract: Mast cells (MC) are specialized exocytic cells that lie beneath the external surfaces of the body. For many decades, MCs were thought to primarily function as effector cells for IgE mediated allergic diseases. However, recent evidence indicates that MCs also function as important cells in immune surveillance. When activated by pathogens, MCs initiate innate and adaptive immune responses thereby resulting in protection against pathogens. The question remains if MC activation may also function in establishing immune responses against allergens and hence allergic disease. New studies suggest that MCs are not only the effector cell of allergy but may also be the initiator of allergy.

[Access This PDF as a
Subscriber](#)
[Purchase/Download This PDF](#)
[Related Articles](#)
[Email This Article](#)
[Share This Article](#)
Introduction

Mast cells (MCs) line the surfaces of the body and possess different receptors which recognize specific components from the outside world. These specialized receptors allow the MC to respond differentially to insults from the external environment. In the case of allergens, MCs have primarily been regarded as effector cells that cause harmful allergic reactions (Hofmann and Abraham, 2008). However, in the case of pathogens, MCs have recently been shown to have an important role in host defense. Pathogen associated MC activation can initiate the innate immune response as well as the adaptive immune response. Given their unique role in immune surveillance against pathogens, the question remains if MCs could potentially play a more central role in the development of immune responses to allergens and hence, allergic disease. New evidence suggests that MCs can participate in the initiation of primary adaptive immune response to allergens, a process known as allergen sensitization. Here, we will briefly review the role of MCs as effector cells of allergic reactions and their more recently described role in promoting protective innate and adaptive immune responses to pathogens. We will then discuss the contribution of MCs in initiating and polarizing the primary immune responses to allergens. Finally, we will describe how microbial infections may severely exacerbate [allergy](#) symptoms in patients by activating MCs.

Role as Harmful Effector Cells During Allergic Responses

MCs have long been recognized as the principle effector cell responsible for IgE mediated allergic reactions. In patients prone to allergies, allergens are recognized, processed, and presented by antigen presenting cells such as dendritic cells to naïve T cells. Naïve T cells that recognize the allergen as foreign then differentiate into [Th2](#) type T cells which produce specific cytokines that cause B cells to synthesize allergen specific IgE. This primary immune response is termed allergen sensitization and has been previously thought to occur without involvement of MCs. The allergen specific IgE then binds to the high affinity IgE receptor (FcεRI) located on the MC surface. Upon re-exposure, the allergen binds and crosslinks IgE-FcεRI on the MC surface resulting in MC degranulation, or release of MC granules. These granules contain preformed mediators such as histamine that cause the symptoms of allergic reactions thereby establishing the MC as the effector cell of allergic diseases (Hofmann and Abraham, 2009). Upon activation by allergen, MCs also begin to synthesize lipid mediators such as prostaglandins and leukotrienes as well as cytokines and chemokines (Hofmann and Abraham, 2009). Prostaglandins and leukotrienes mediate some of the symptoms of allergic diseases such as bronchoconstriction. The cytokines and chemokines secreted by MCs recruit inflammatory cells such as eosinophils, basophils, and T cells to the site of allergen exposure. These cells then participate in the late phase response to allergen and promote many of the well known pathological sequelae associated with allergy (Hofmann and Abraham, 2009).

Initiator of Innate Immune Responses and Adaptive Immune Responses to Invading Pathogens

MCs line the surfaces of the body including the respiratory tract, the gastrointestinal tract, genitourinary tract, and the skin and are in prime position to recognize invading pathogens. To function as immune surveillance cells, MCs have developed at least 3 mechanisms of pathogen recognition: (i) Direct binding of pathogens or their components by pathogen associated molecular pattern (PAMP) receptors located on the MC surface; (ii) binding of antibody or complement coated bacteria by complement receptors or immunoglobulin receptors, or (iii) recognition of endogenous peptides produced by infected or injured host cells (Hofmann and Abraham, 2009). Depending on the type of receptor engaged on the MC surface, different immune responses to the pathogen are triggered (Qiao et al., 2006).

One important and much studied class of PAMP receptors are the Toll like receptors (TLRs). The two most studied TLRs on MCs are TLR 2 and TLR 4 (Varadaradjalou et al., 2003; McCurdy et al., 2003). TLR 2 recognizes peptidoglycan from gram positive bacteria, gram negative bacteria, and mycobacteria, and zymosan from yeast. TLR 4 binds to lipopolysaccharide (LPS) from gram negative bacteria, lipid A, fibrinogen, and *Mycobacterium tuberculosis* (Varadaradjalou et al., 2003). When TLR 2 or TLR 4 is engaged, human MCs release cytokines which recruit immune cells to the sites of infection such as neutrophils which then destroy the pathogen (Varadaradjalou et al., 2003; McCurdy et al., 2003). Studies have shown that MC deficient mice are less able than wild-type mice to clear *Escherichia coli* in an acute peritonitis model, and *Klebsiella pneumoniae* and *Francisella tularensis* in a lung infection model. In all of these models, MC deficient mice have decreased survival due to impaired innate host responses thereby indicating that MCs are critical to the innate immune response against pathogens (Malaviya et al., 1999; Ketavarapu et al., 2008; Sutherland et al., 2008).

MCs also have profound effects on two of the central cells of [adaptive immunity](#): dendritic cells and T cells. Dendritic cells or antigen presenting cells are recruited to sites of pathogen invasion where they take up pathogen components, or antigens. They then travel to nearby lymph nodes where they present the antigen to naïve T cells. These stimulated naïve T cells then differentiate into different [T cell](#) subsets, each with their own function in fighting pathogens. Interestingly, MCs have been shown to modulate the activities of both dendritic cells and T cells (Galli et al., 2005). In order to establish an adaptive immune response, dendritic cells laden with antigen must travel from infection sites to lymph nodes where they mature and interact with T cells. Studies have shown that pathogens at infection sites stimulate MC degranulation which releases pre-stored [tumor necrosis factor \$\alpha\$](#) (TNF- α), a cytokine which functions to guide dendritic cells first to infection sites and then to lymph nodes (Suto et al., 2006; McLachlan et al., 2003). In addition to its local action, MC derived TNF- α also drains to nearby lymph nodes and attracts T cells from the blood to the nodes (Kunder et al., 2009). The T cells are then in prime position to engage dendritic cells entering lymph nodes from the infection sites. This interaction of T cells and dendritic cells in the lymph nodes as coordinated by MCs begins the adaptive immune response.

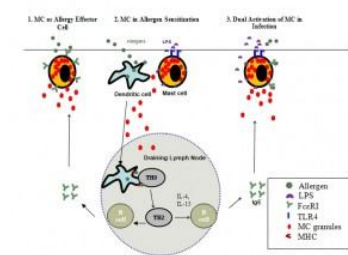


Figure 1. Mast Cell Roles in Allergic Disease 1. MCs degranulate when allergen binds to IgE on the MC surface. 2. MCs play a key role in allergen sensitization when allergen exposure occurs in the presence of bacterial byproducts. 3. Allergen and bacterial products act synergistically to increase MC granule release.

MCs may also influence the type of adaptive immune response made to a pathogen through cytokine secretion. Upon activation, MCs release cytokines such as [IL-4](#) and [IL-13](#) which can induce a stimulated naïve T cell to become a Th2 type T cell which can then drive antibody responses as described previously. In support of this concept, one study has shown that MC activators, when paired with an antigen, can induce strong antibody responses in the host that are protective against pathogen challenge (McLachlan et al., 2008).

MCs can also directly activate T cells by functioning as antigen presenting cells under certain conditions. When complement and antibody receptors on the MC surface bind bacteria coated with complement or antibody, the MC can then endocytose these bacteria, break them down, and express bacterial antigens in association with MHC I, one of the co-stimulatory molecules for T cells, on the MC surface (Malaviya et al., 1996). The co-expression of MHC I and bacterial antigens by MCs activates [CD8](#) T cells which then can kill infected host cells (Malaviya et al., 1996). Studies suggest that MCs may also be able to act as antigen presenting cells to activate other types of naïve T cells, namely CD4 T cells which are important in coordination of immune cells and in antibody responses such as those in allergy (Nakano et al., 2009; Kambayashi et al., 2009). In summary, MCs initiate and coordinate the adaptive immune response by directing migration of dendritic and T cells to lymph nodes, by secreting T cell polarizing cytokines, and possibly by direct antigen presentation to T cells.

Initiator of the Primary Immune Responses to Allergens

Over the past decade, ample evidence has accumulated showing the critical role that MCs play in immune responses to pathogens, or dangerous foreign substances. Less is known about the role of MCs in initiating innate and adaptive immune responses to innocuous substances such as pollen or food. However, new evidence is emerging to suggest that MCs may coordinate and drive a Th2 immune response to innocuous agents particularly when these innocuous agents are encountered in the setting of [endotoxin](#) exposure thereby resulting in allergen sensitization (Eisenbarth et al., 2002; Nigo et al., 2006). Endotoxins and peptidoglycan are common contaminants in the environment and can act on MCs via TLRs as described previously. When an individual encounters allergen and low doses of endotoxin or peptidoglycan in the environment simultaneously, MC activation through TLR signaling may lead to MC secretion of cytokines such as TNF- α into the local environment. Dendritic cells which have taken up the innocuous allergen may then become activated by TNF- α and may migrate to the [lymph node](#) where they activate T cells thereby leading to an inappropriate Th2 immune response to the innocent allergen in a “bystander phenomenon” resulting in allergen sensitization (Eisenbarth et al., 2002; Nigo et al., 2006). Thus in this scenario, the endotoxin or peptidoglycan serves as a powerful adjuvant potentiating an immune response to allergens. Furthermore, the critical role that MCs play in defense against pathogens is counterproductive here as it induces allergic sensitization.

Recent evidence from mouse studies suggests that MCs may indeed function in allergic sensitization. In a mouse model of [asthma](#), intranasal administration of low doses of lipopolysaccharide (LPS), or endotoxin, in association with antigen resulted in increased [eosinophil](#) infiltration into the lungs which is a marker of asthma. Wild-type mice treated with antigen alone had less eosinophils in their lungs (Nigo et al., 2006). When these studies were performed in MC deficient mice, eosinophil accumulation failed to occur in response to LPS and antigen and was only restored when the MC deficient mice were reconstituted with wild-type MCs. Interestingly eosinophils failed to accumulate in MC deficient mice reconstituted with TLR 4 [knockout](#) MCs (Nigo et al., 2006). These experiments suggest that in the setting of TLR 4 activation by low doses of endotoxin, MCs are critical to the induction of Th2 T cell responses to allergens, or to allergen sensitization.

Exacerbations of Allergic Diseases

Infections have been shown to exacerbate allergic diseases, especially asthma and [atopic dermatitis](#). These exacerbations may be due to dual activation of the MC both by allergen and by pathogen. When the MC encounters an allergen and a pathogen at the same time, IgE receptors and PAMPs on the MC surface may be simultaneously activated thereby enhancing the MC response and exacerbating allergic disease. Studies have shown that dual activation of TLRs by bacterial products and the IgE receptor by allergen acts synergistically to increase cytokine production by MCs which may increase allergic disease (Qiao et al., 2006). For example, release of augmented amounts of TNF- α from MCs activated by pathogens and by allergens may increase bronchial contractility and worsen asthma. Atopic dermatitis, an allergic condition of the skin, may also be exacerbated by dual activation of MCs. Approximately 90% of patients with atopic dermatitis have skin colonization with *Staphylococcus aureus*, a gram positive bacterium, which contains peptidoglycan (Abeck and Mempel, 1998). Peptidoglycan may bind to TLR 2 on MCs in the skin at the same time as binding of allergens from the environment to the FcεRI on MCs thereby markedly enhancing release of proinflammatory cytokines which worsens the skin disease (Supajatura et al., 2002). Overall, activation of TLR signaling in addition to IgE receptor signaling in the setting of infection and allergen exposure causes enhanced MC activation and worsening of established allergic disease.

MCs may also amplify exacerbations of allergic disease in the absence of infection through their potential ability to act as antigen presenting cells. MCs may act similarly to B cells and participate in a process termed facilitated antigen binding (Wilcock et al., 2006). In a facilitated antigen binding model, allergens bound to the IgE-FcεRI on the MC surface would be endocytosed, processed, and presented in association with MHC I or even perhaps MHC II on the MC surface. MCs bearing allergen-MHC complexes could then stimulate allergen specific T cells leading to proliferation, cytokine secretion, and enhancement of allergic disease.

Conclusions

For many years, MCs were considered merely as the effector cells of the allergic response. Within the last decade, a new role for MCs in defense against pathogens has been described. We now know that MCs play a critical function in both the initiation of the innate immune response and in coordination of the adaptive immune response. For pathogens, this response is protective. For allergens, this response may be harmful and may result in establishment and exacerbation of allergic disease. By further defining the role of the MC in both innate and adaptive immune defense, we will likely begin to understand the multidimensional role of the MC in allergy as well. These insights will likely lead to new treatments for allergic disease.

References

- Eisenbarth SC, Piggot DA, Huleatt JW, Visintin I, Herrick CA, Bottomly K. Lipopolysaccharide-enhanced, [Toll-like receptor](#) 4-dependent T helper cell type 2 responses to inhaled antigen. *J Exp Med* 196(12):1645-51, 2002.
- Galli SJ, Nakae S, Tsai M. Mast cells in the development of adaptive immune responses. *Nat Immunol* 6(2):135-42, 2005.
- Hofmann AM, Abraham SN. New roles for mast cells in modulating allergic reactions and immunity against pathogens. *Curr Opin Immunol* 21(6):679-86, 2009.
- Kambayashi T, Allenspach EJ, Chang JT, Zou T, Shoag JE, Reiner SL, Caton AJ, Koretzky GA. Inducible MHC class II expression by mast cells supports effector and [regulatory T cell](#) activation. *J Immunol* 182(8):4686-95, 2009.
- Ketavarapu JM, Rodriguez AR, Yu JJ, Cong Y, Murthy AK, et al. Mast cells inhibit intramacrophage *Francisella tularensis* replication via contact and secreted products including IL-4. *Proc Natl Acad Sci USA* 105(27):9313-8, 2008.
- Kunder CA, St John AL, Li G, Leong KW, Berwin B, Staats HF, Abraham SN. Mast cell-derived particles deliver peripheral signals to remote lymph nodes. *J Exp Med* 206(11):2455-67, 2009.
- Malaviya R, Gao Z, Thankavel K, van der Merwe PA, Abraham SN. The mast cell [tumor necrosis factor alpha](#) response to FimH-expressing *Escherichia coli* is mediated by the glycosylphosphatidylinositol-anchored molecule CD48. *Proc Natl Acad Sci USA* 96(14):8110-5, 1999.
- Malaviya R, Twesten NJ, Ross EA, Abraham SN, Pfeifer JD. Mast cells process bacterial Ags through a phagocytic route for class I MHC presentation to T cells. *J Immunol* 156(4):1490-6, 1996.
- McCurdy JD, Olynich TJ, Maher LH, Marshall JS. Cutting edge: distinct Toll-like receptor 2 activators selectively induce different classes of mediator production from human mast cells. *J Immunol* 170(4):1625-9, 2003.
- McLachlan JB, Hart JP, Pizzo SV, Shelburne CP, Staats HF, Gunn MD, Abraham SN. Mast cell-derived tumor [necrosis](#) factor induces hypertrophy of draining lymph nodes during infection. *Nat Immunol* 4(12):1199-205, 2003.
- McLachlan JB, Shelburne CP, Hart JP, Pizzo SV, Goyal R, Brooking-Dixon R, Staats HF, Abraham SN. Mast cell activators: a new class of highly effective vaccine adjuvants. *Nat Med* 14(5):536-41, 2008.
- Nakano N, Nishiyama C, Yagita H, Koyanagi A, Akiba H, Chiba S, Ogawa H, Okumura K. Notch signaling confers [antigen-presenting cell](#) functions on mast cells. *J Allergy Clin Immunol* 123(1):74-81, 2009.
- Nigo YI, Yamashita M, Hirahara K, Shinnakasu R, Inami M, Kimura M, Hasegawa A, Kohno Y, Nakayama T. Regulation of [allergic airway inflammation](#) through Toll-like receptor 4-mediated modification of mast cell function. *Proc Natl Acad Sci USA* 103(7):2286-91, 2006.
- Qiao H, Andrade MV, Lisboa FA, Morgan K, Beaven MA. FcεpsilonR1 and toll-like receptors mediate synergistic signals to markedly augment production of inflammatory cytokines in murine mast cells. *Blood* 107(2):610-8, 2006.
- Rao KN, Brown MA. Mast Cells: multifaceted immune cells with diverse roles in health and disease. *Ann NY Acad Sci* 1143:83-104, 2008.
- Supajatura V, Ushio H, Nakao A, Akira S, Okumura K, Ra C, Ogawa H. Differential responses of mast cell Toll-like receptors 2 and 4 in allergy and [innate immunity](#). *J Clin Invest* 109(10):1351-9, 2002.
- Sutherland RE, Olsen JS, McKinstry A, Villalta SA, Wolters PJ. Mast cell [IL-6](#) improves survival from *Klebsiella pneumoniae* and [sepsis](#) by enhancing [neutrophil](#) killing. *J Immunol* 181(8):5598-605, 2008.
- Varadaradjalou S, Féger F, Thieblemont N, Hamouda NB, Pleau JM, Dy M, Arock M. Toll-like receptor 2 (TLR2) and [TLR4](#) differentially activate human mast cells. *Eur J Immunol* 33(4):899-906, 2003.
- Wilcock LK, Francis JN, Durham SR. IgE-facilitated antigen presentation: role in allergy and the influence of [allergen immunotherapy](#). *Immunol Allergy Clin North Am* 26(2):333-47, 2006.
- [Discovery Medicine, 9(45):79-83, February 2010]

Related Articles

- Oct 14, 2011 [Peanut Allergy: An Evolving Clinical Challenge](#)
 - Oct 25, 2010 [Sublingual Specific Immunotherapy](#)
 - Apr 25, 2010 [The Role of Eosinophils in Allergic Airway Inflammation](#)
 - Apr 05, 2011 [Novel Cytokine-directed Therapies for Asthma](#)
 - Jan 14, 2011 [The Genetics of Asthma and Allergic Disorders](#)
 - Jun 22, 2010 [Overcoming Dendritic Cell Tardiness to Triumph over IL-13 Receptor: A Strategy for the Development of Effective Pediatric Vaccines](#)
 - Apr 07, 2011 [Autoantigen Based Vaccines for Type 1 Diabetes](#)
 - Aug 30, 2010 [A Role for Lysophosphatidic Acid and Sphingosine 1-Phosphate in the Pathogenesis of Systemic Sclerosis](#)
 - Mar 03, 2010 [mTOR Signaling: A Central Pathway to Pathogenesis in Systemic Lupus Erythematosus?](#)
 - Jul 25, 2009 [Lactobacilli as Natural Enhancer of Cellular Immune Response](#)
- [More Related Articles](#)

[Access This PDF as a Subscriber](#) | [Purchase/Download This Article](#)

Categories: [Allergy](#), [Atopic Dermatitis](#), [Dendritic Cell](#), [Eosinophil](#), [Mast Cell](#), [T Cell](#), [Type 2 T Helper Cell](#)

Tags: [endotoxin](#), [leukotriene](#), [prostaglandin](#), [Toll-like receptor](#)

Search

[Search Tips/Help](#)

Journal Issues - Current & Archive (Part)

Current Issue, No 067, Dec. 2011 | [No 066, Nov. 2011](#) | [No 065, Oct. 2011](#) | [No 064, Sep. 2011](#) | [No 063, Aug. 2011](#) | [No 062, Jul. 2011](#) | [No 061, Jun. 2011](#) | [No 060, May 2011](#) | [No 059, Apr. 2011](#) | [No 058, Mar. 2011](#) | [No 057, Feb. 2011](#) | [No 056, Jan. 2011](#) | [No 055, Dec. 2010](#) | [No 054, Nov. 2010](#) | [No 053, Oct. 2010](#) | [No 052, Sep. 2010](#) | [No 051, Aug. 2010](#) | [No 050, Jul. 2010](#) | [No 049, Jun. 2010](#) | [No 048, May 2010](#) | [No 047, Apr. 2010](#) | [No 046, Mar. 2010](#) | [No 045, Feb. 2010](#) | [No 044, Jan. 2010](#) |

Global Categories**Medical Specialties**

[Addiction Medicine](#) [Aging](#) [Anesthesiology](#) [Bacteriology](#) [Cardiology](#) [Cardiology and Circulation](#) [Dermatology](#) [Drug Discovery](#) [Endocrinology](#) [Epidemiology](#) [Gastroenterology](#) [Genomic Medicine](#) [Geriatrics](#) [Gerontology](#) [Gynecology](#) [Hematology](#) [Hepatology](#) [Immunology](#) [Infectious Diseases](#) [Medical Genetics](#) [Microbiology](#) [Mycology](#) [Nephrology](#) [Neurology](#) [Neurosurgery](#) [Nutrition](#) [Oncology](#) [Ophthalmology](#) [Orthopedics](#) [Otolaryngology](#) [Pathology](#) [Pediatrics](#) [Personalized Medicine](#) [Pharmacogenetics](#) [Pharmacogenomics](#) [Pharmacology](#) [Plastic and Reconstructive Medicine](#) [Preventive Medicine](#) [Psychiatry](#) [Psychology](#) [Pulmonology](#) [Radiology](#) [Regenerative Medicine](#) [Reproductive Medicine](#) [Rheumatology](#) [Surgery](#) [Toxicology](#) [Traditional Chinese Medicine](#) [Translational Research](#) [Transplantation](#) [Urology](#) [Virology](#)

Life Sciences

[Anatomy](#) [Anthropology](#) [Biochemistry](#) [Bioinformatics](#) [Biology](#) [Biophysics](#) [Cell Biology](#) [Chemistry](#) [Developmental Biology](#) [Ecology](#) [Embryology](#) [Environmental Science](#) [Epigenetics](#) [Genetics](#) [Genomics](#) [Glycomics](#) [Molecular Biology](#) [Neuroscience](#) [Physiology](#) [Plant Biology](#) [Proteomics](#)

Species and Cell Types

[Bacterium](#) [Fungus](#) [Human](#) [Other Species](#) [Parasite](#) [Rodent](#) [Streptococcus gordonii](#) [Virus](#)

Research Technology

[Antibody Production](#) [Biotin-Avidin Technology](#) [Bispecific Antibody](#) [Carbohydrate](#) [Cell Culture](#) [Cell Fusion](#) [Cell Tracking](#) [In Vivo Cellular Electrophysiology](#) [Chemiluminescence](#) [Combinatorial Chemistry](#) [Disease Gene Discovery](#) [Drug Delivery](#) [Flow Cytometry](#) [Gene Knockout](#) [Gene Targeting](#) [Gene Transfer](#) [Genetic Engineering](#) [High Throughput Screening](#) [Imaging](#) [Immunotechnology](#) [Microscopy](#) [Molecular Engineering](#) [Molecular Profiling](#) [Nanotechnology](#) [Nuclear Magnetic Resonance](#) [Nuclear Transfer](#) [Nucleic Acid](#) [Organism](#) [Cloning](#) [Protein](#) [RNA Interference](#) [Stem Cell Technology](#) [Tissue Engineering](#) [Transgenic Technology](#) [X-Ray Crystallography](#)

Therapeutic Technology and Methodology

[Diagnosis](#) [Experimental Therapy](#) [Therapy](#)

Pharmaceutical and Healthcare Industry

[Biotechnology](#) [Commercialization of Discoveries](#) [FDA Drug Regulation](#) [Pharmaceutical Industry](#)

Global Tags**List of 100 Random Tags: (or [View All Tags](#))**

[14-3-3](#) [adenosine deaminases acting on RNA](#) [Adrenocorticotrophic hormone](#) [AMG 785](#) [amyloid precursor protein](#) [anti-angiogenesis](#) [antibody production](#) [antigen-presenting cell](#) [antioxidant](#) [antithrombosis](#) [APP](#) [arginine rich motif](#) [ATA B7-1](#) [BCG](#) [BCR](#) [BCR-ABL](#) [tyrosine kinase](#) [beta-catenin](#) [beta tubulin III](#) [Biogen Idec](#) [black box](#) [BMP-2](#) [body mass index](#) [bone morphogenetic protein](#) [BRAF](#) [catalytic antibody](#) [complementarity-determining region](#) [CRP](#) [CTL](#) [CXCL12](#) [cytochrome c oxidase](#) [DC-SIGN](#) [deoxyguanosine triphosphate](#) [disease prognosis](#) [DNA methylation](#) [Eosinophilia](#) [eplerenone](#) [estriol](#) [fixed-dose artemisinin combination therapy](#) [Flt3L](#) [FOXP2](#) [galactosyltransferase](#) [gene vector](#) [gp120](#) [HBeAg](#) [HDL-C](#) [histone deacetylase](#) [histone deacetylase inhibitor](#) [HPV-16](#) [hydrogel](#) [IFN-gamma](#) [IL-15](#) [IL-6](#) [IL-7](#) [immunodeficiency](#) [inhibitory neurotransmission](#) [l oligomer](#) [lysosome](#) [micrometastasis](#) [miRNA](#) [mocetinostat](#) [molecular evolution](#) [mTOR](#) [Na-K ATPase](#) [ncRNA](#) [neuroprotection](#) [NFAT1](#) [NSAIDs](#) [nuclear transplantation](#) [orexin](#) [osteopontin](#) [oxidative stress](#) [p21](#) [PD-1](#) [PDE](#) [platelet-derived microparticle](#) [progesterone receptor](#) [programmed cell death](#) [protein kinase C](#) [racial profiling](#) [radiopharmaceutical](#) [reactive oxygen species](#) [reproductive cloning](#) [resolvase](#) [sequence homology analysis](#) [shiga toxin](#) [siRNA](#) [SIRT1](#) [SNP mapping](#) [systems biology](#) [T cell receptor](#) [tadalafil](#) [therapeutic gene](#) [tissue plasminogen activator](#) [tumor associated antigen](#) [type I receptor](#) [tyrosine kinase](#) [uniparental disomy](#) [VKORC1](#) [X-linked gene](#) [Yttrium-90](#)

Copyright 2012, [Discovery Medicine](#). All Rights Reserved.