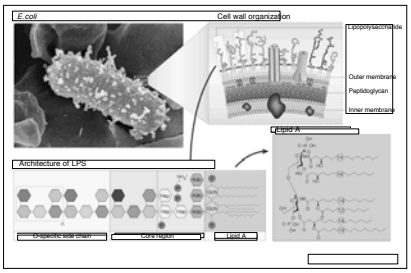
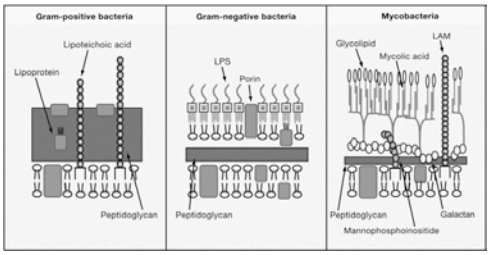
The Innate Immune Response is Conserved Throughout Evolution and is Triggered by Pattern Recognition

## Lipopolysaccharide = Lipid + Polysaccharide




From: Beutler and Rietschel, *Nature Reviews Immunology* **3**; 169-176 (2003)

## Diversity of Pathogen-associated Molecular Patterns (PAMPs)

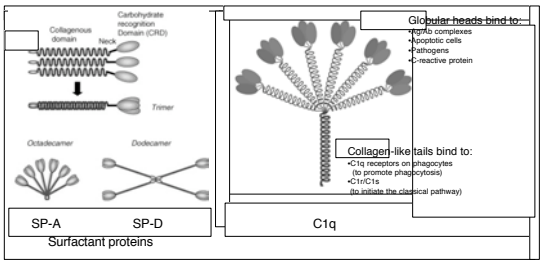



From: Akira et al., *Cell* 124:783, 2006

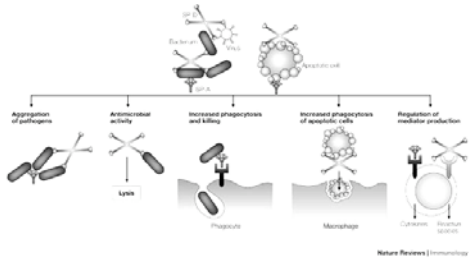
## Innate Immune Receptors for PAMPs

- Toll-like receptors (TLRs)
- Complement
- Collectins (e.g., Surfactant Protein-A)
- Scavenger receptors
- Pentraxins (e.g., CRP)
- Lectins (e.g., Dectin-1)
- CD14
- NOD-like receptors (NLRs)
- RIG-1-like receptors

## Collectins and Innate Immune Recognition

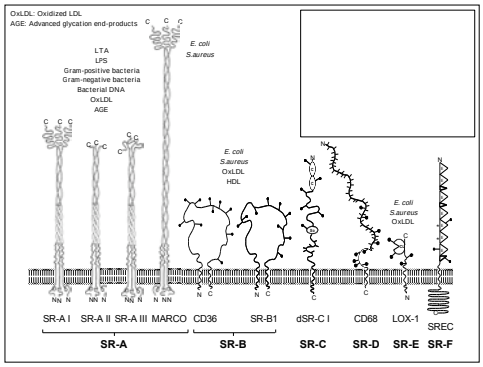



## Some Functions of Collectins

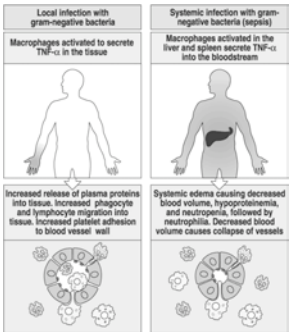



From: Wright, *Nature Rev. Immunol.* **5**:58, 2005

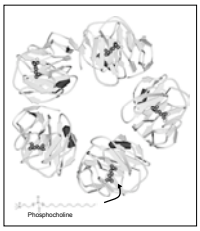
## The Scavenger Receptor Superfamily Recognizes PAMPs

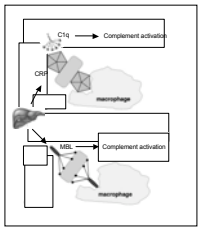



## Innate Immune Receptors Also Trigger a Systemic Response to Infection




## Innate Immune Functions of C Reactive Protein (CRP), an Acute Phase Protein Synthesized by Hepatocytes

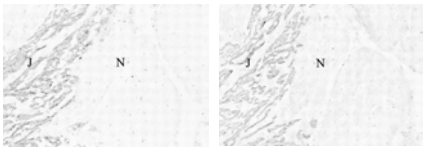



CRP acts as a bridge between phosphocholine on bacterial targets and C1q

Adapted from: Black et al., *J. Biol. Chem.* 47:48487, 2004

## Co-localization of CRP and Activated Complement in Infarcted Human Myocardium

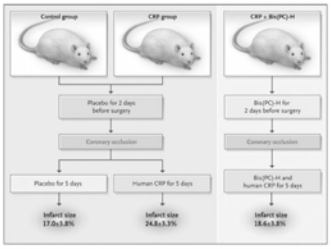



CRP C4d

J = jeopardized; N = normal

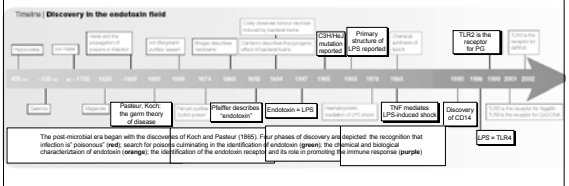
From: Nijmeijer et al., *Am. J. Pathol.* 163:269, 2003

## Treatment of Experimental Myocardial Infarction with a CRP-binding Analog of Phosphocholine Limits Infarct Size




From: Kitsis and Jialal, *New Engl. J. Med.* 355:513, 2006

## History of Endotoxin Research



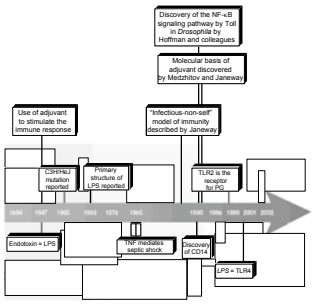

Modified from: Beutler and Rietschel, *Nature Reviews Immunology* **3**; 169-176 (2003)



letters to nature

A human homologue of the *Drosophila* Toll protein signals activation of adaptive immunity

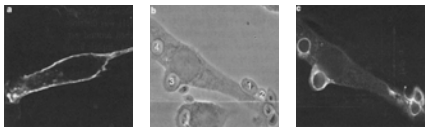
## A Re-interpretation of the Endotoxin Research Timeline




Modified from: Beutler and Rietschel, *Nature Reviews Immunology* **3**; 169-176 (2003)

## Primitive Specificity in Target Recognition by the Innate Immune System

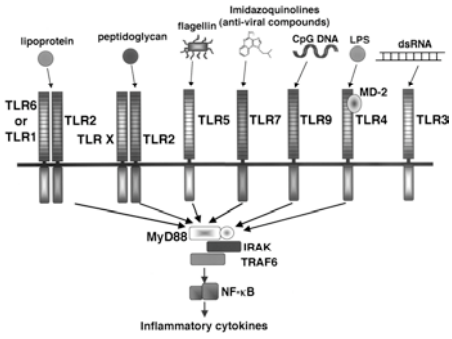
## Recruitment of TLR2 to Yeast Phagosomes



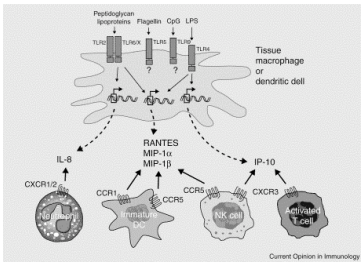
**TLR2** **Phase Contrast** **TLR2**

From: Underhill et al., *Nature* 401:811, 1999

## Ligand Specificity of TLRs



## Specificity of TLR Transcriptional Programs




From: Luster, *Curr. Opin. Immunol.* 14:129, 2002

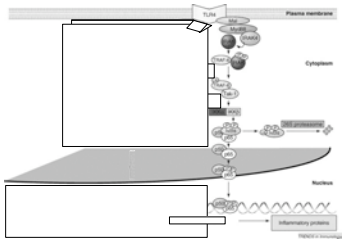
## TLR Signaling: Two Major Pathways

Cartoon of major signal transduction pathways following engagement of TLRs. TLR4 is the major sensor of LPS. TLR3 recognizes dsRNA and is important in the anti-viral response. The IRF pathway leading to production of Type I IFNs (i.e., IFN-α/β) is particularly prominent in a minor subset of dendritic cells (called "plasmacytoid DCs") that are the major source of these IFNs in response to viral infections.

Do <u>not</u> memorize this cascade but rather appreciate that it consists of two parallel pathways, one that activates NF-κB, leading to production of pro-inflammatory proteins, and one that activates the IRF pathway, leading to production of Type I IFNs.

From: Moynagh, *Trends Immunol.* 26:469, 2005

## TLR Signaling: Two Major Pathways



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Do <u>not</u> memorize this cascade but rather appreciate that it consists of two parallel pathways, one that activates NF-κB, leading to production of most pro-inflammatory proteins, and one that activates the IRF pathway, leading to production of Type I IFNs.

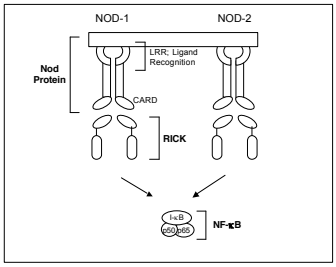
From: Moynagh, *Trends Immunol.* 26:469, 2005

## TLRs Sense Microbial Pathogens and Trigger Expression of Pro-inflammatory Cytokines and Chemokines


Adapted from: Creagh and O'Neill, *Trends Immunol.* 27:352, 2006

## Newly Recognized Components of the Innate Immune System

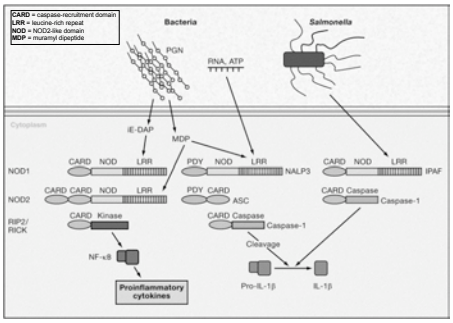
## NOD Proteins: Intracellular Peptidoglycan Sensors




Polymorphisms in *Nod-2* are associated with up to 30-40% of cases of Crohn's disease (an inflammatory bowel disease)

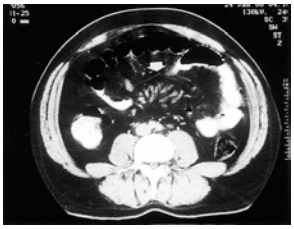
**CARD**, caspase-recruitment domain; **LRR**, leucine-rich repeat; **RICK**, a CARD-containing protein kinase

## Cytosolic Bacterial Recognition Systems and "the Inflammasome"



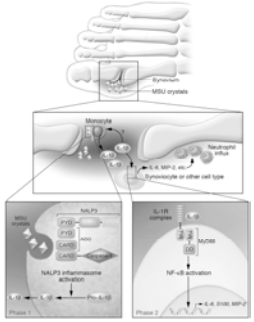

From: Akira et al., *Cell* 124:783, 2006

## Mutations in Pyrin, Another CARD-containing Innate Immune-like Protein, is Responsible for Familial Mediterranean Fever



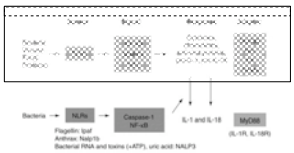
Contrast-enhanced abdominal CT from a 31 year-old patient with Familial Mediterranean Fever suffering an acute attack of abdominal pain, nausea, vomiting, and arthritis. Note mesenteric vessel with thickened mesenteric fold (*white arrow*). Histopathology demonstrated neutrophilic infiltrate and associated vasculitis. Treatment with an IL-1 receptor antagonist (Anakinra) resulted in prompt cessation of symptoms.

## Pathogenesis of Gout Uncovered in 2006: Monosodium urate crystals activate the inflammasome




From: Martinon and Glimcher *J. Clin. Invest.* 116:2073, 2006

## Nod-like Receptors (NLRs) Sense Microbial Products, Activate the "Inflammasome," and Trigger Maturation of IL-1

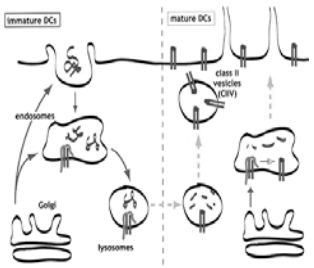



Adapted from: Creagh and O'Neill, *Trends Immunol.* 27:352, 2006

## The Dendritic Cell and Development of The Primary Immune Response:

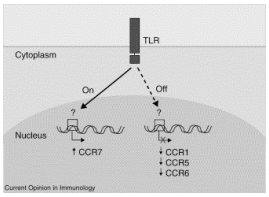
## Wisdom Through Maturity

## Dendritic Cell Maturation



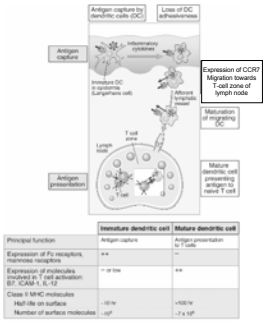

From: Mellman & Steinman, *Cell* 106:255, 2001

## The Innate Immune Response Orchestrates DC Trafficking to Secondary Lymphoid Organs

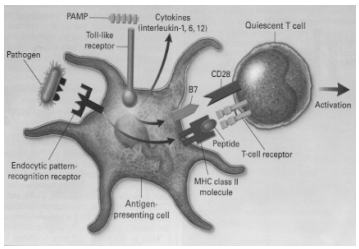



From: Luster, *Curr. Opin. Immunol.* 14:129, 2002

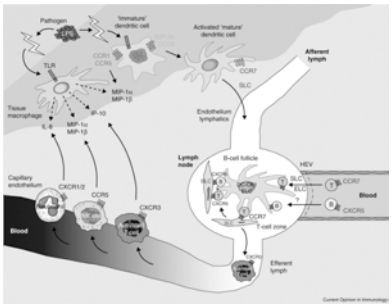
## Functional Differences Between Immature and Mature DCs




## The (Primary) Acquired Immune Response is Initiated by Innate Immune Recognition

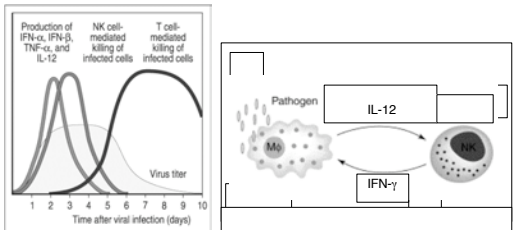



## Chemokines Direct Trafficking of Immune Cells

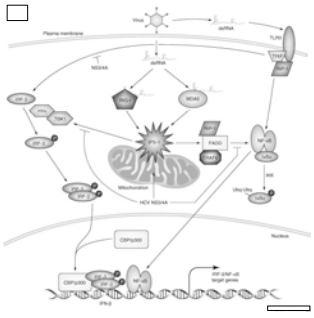



From: Luster, *Curr. Opin. Immunol.* 14:129, 2002

## The Early Antiviral Response: Cytokines of the Innate Immune System




## Innate Immune Receptors for dsRNA Cooperate to Initiate the Immune Response to RNA Viruses

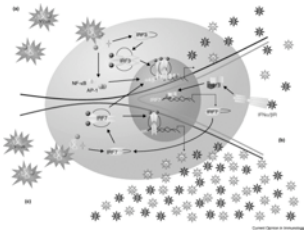


Double-stranded RNA products of virus infection bind to RIG-I or MDA5, which in turn bind to IPS-1 via CARD domain interactions. This complex then signals the activation of IKK-ε and TBK1 or other kinases to phosphorylate IRF-3, possibly through direct recruitment of signaling effectors, leading to IRF-3 dimerization, nuclear translocation and assembly onto the IFN-β enhancer. IPS-1 might also signal the activation of the IKK complex via direct binding of IKK components or through recruitment of RIP-1, FADD and/or TRAF6, causing the phosphorylation of IκB, the inhibitor of NF-κB. Phosphorylated IκB is then ubiquitinated and targeted to the proteosome for degradation, releasing the active NF-κB complex to translocate to the nucleus. During virus infection, dsRNA products can signal through TLR3 to activate IRF-3 and NF-κB by the actions of the TRIF adaptor protein and RIP-1, respectively.

N.B.: Do not memorize this cartoon, but appreciate how cytosolic dsRNA receptors (RIG-1, MDA5) and plasma membrane-associated dsRNA receptors (TLR3) cooperate to activate IRF- and NF-κB-dependent gene expression.

From: Johnson and Gale, *Trends Immunol.* 27:1, 2006

## The Antiviral Response: a Cascade of Transcriptional Events

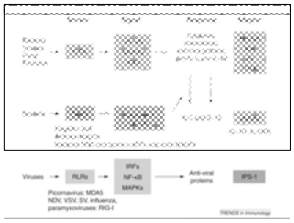


Some targets of IRFs

| Gene | Function |
|---|---|
| p21 | Cell cycle arrest |
| IL-15 | NK cell maturation |
| FasL | Cell death |
| IL-12 | Th1 immune response |

Multiphasic induction of murine type I IFN genes can be divided into three phases. (a) The immediate early phase. Virus infection stimulates a phosphorylation cascade, leading to the activation of at least three families of transcription factors, including NF-κB, AP-1 and IRF3. Activation of the IFN-α promoter requires all three transcription factors. (b) IRF7 induction phase. Secretion of early IFN produces an autocrine response through stimulation of the JAK-STAT pathway. Among the pathway's target genes is IRF7, itself. (c) Delayed early (amplification) phase. Many members of the IFN-α gene family possess promoter binding sites for activated IRF7 and become transcriptionally active.

## RIG-1-like Receptors (RLRs) Sense Viral Products, Activate the IRF Pathway, and Trigger and Trigger Production of Antiviral Proteins




Adapted from: Creagh and O'Neill, *Trends Immunol.* 27:352, 2006

## Summary

1. Innate immunity is conserved throughout evolution and is triggered by recognition of "pathogen-associated molecular patterns" (e.g., LPS) by "pattern recognition receptors."
2. Collectins (e.g., SP-A, C1q, MBP) recognize carbohydrates on pathogen surfaces and perform multiple anti-microbial functions (e.g., opsonization). Collectins are essential for innate immunity, but also help clear apoptotic debris.
3. Members of the Scavenger Receptor superfamily recognize bacteria as well as glucose-modified proteins and oxidized lipoproteins. They are implicated in the response to infection as well as atherosclerosis and other degenerative diseases.
4. TLR4 is the major LPS receptor in mammalian cells. TLR4 triggers activation of NF-κB (leading to production of TNF-α, for example). Other TLRs recognize additional microbial products. NOD-like receptors (NLRs) are intracellular sensors of bacterial products that activate the "inflammasome," triggering caspase-dependent maturation of IL-1.
5. Dendritic cells undergo a maturation program: immature DCs, which traffic to the periphery, capture antigen, and mature DCs, which traffic to the lymph node, present antigen. Innate immune stimuli trigger DC maturation, which upregulates co-stimulatory molecules and facilitates antigen presentation. Thus, the innate immune response ushers in the acquired immune response.
6. NK cells, a component of innate immunity, especially to viruses, represent an early source of IFN-γ and serve to stimulate macrophages and DCs in inflammatory sites. Additional components of the antiviral response include intracellular dsRNA sensors (RIG-like proteins) that activate the IRF pathway to signal antiviral gene expression.