Phagocytic Cells: Mechanisms of Bacterial Killing and Tissue Injury

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Phagocytic Cells: Mechanisms of Bacterial Killing and Tissue Injury

• Learning Outcomes:
  – To understand the pathophysiologic role of phagocytic cells in host defense.
  – To understand the role of reactive oxygen metabolites and lysosomal granules in phagocytic cell function.
Phagocytic Cells

• Peripheral Blood Leukocytes (nrml. 4.5-11,000 cells/ul)
  – Lymphocytes (~ 30%)
  – Granulocytes (~ 70%)

• Granulocytes:
  – **Neutrophils** (~ 60% of total leukocytes in blood)
  – Eosinophils (~ 3%)
  – Basophils (<1%, rare)
  – **Monocytes** (~ 6%)

• Kupffer cells (lining liver sinusoids)
Peripheral Blood Smear

Neutrophil

Lymphocyte

Source: Undetermined
Monocyte

Source: Undetermined
Neutrophils and Macrophages

• Function:
  – Ingest foreign material
  – Kill bacteria and other microbes
  – Degrade necrotic tissue and foreign antigens

• Tissue damage during prolonged inflammation
Neutrophil Recruitment

Selectins/Addressins $\rightarrow$ $\beta_2$-Integrin/ICAM-1

flow $\rightarrow$ rolling $\rightarrow$ adhesion $\rightarrow$ transmigration

Tissue Injury (e.g. Bacterial infection)

inflammatory mediators

endothelium

• phagocytosis
• oxidant production
• lysosomal granules

chemoattractant (e.g. IL-8, C5a)
Phagocytic Cell Activation: Chemotactic Factors

C5a

plasma membrane

G-protein tyrosine kinases

protein phosphorylation

phosphoinositol metabolism

↑ IP3

↑ Ca^{2+}

functional responses

Other receptors:
Toll-like receptor
Mannose receptor
Phagocytic Cell Functional Responses

- Adhesion (localization)
- Chemotaxis (migration)
- Phagocytosis
- NADPH oxidase activation
- Lysosomal granule fusion: degranulation
Opsonization and Phagocytosis

- Fc receptors for antibody
- Complement receptors: (e.g. C3b)
- Other
  - receptors for collectins (e.g. mannose-binding protein)
NEUTROPHIL PHAGOCYTOSIS OF OPSONIZED BACTERIA

Source: Undetermined
cell phagocytosis

Oxygen radicals

Elastase
Collagenase
Acid hydrolases

Source: Undetermined
Respiratory Burst: NADPH Oxidase

![Graph showing Oxygen Levels (% of max.) over time for normal and patient conditions. The graph includes a stimulus added at time 0 and a comparison between normal and patient oxygen levels.](image-url)
**Reactive Oxygen Metabolites**

- **Superoxide anion:** $O_2^-$
  
  $$O_2 + e^- \rightarrow O_2^-$$

- **Hydrogen peroxide:** $H_2O_2$
  
  $$2O_2^- + 2H^+ \rightarrow H_2O_2 + O_2$$

- **Hydroxyl radical:** $OH.$
  
  $$H_2O_2 + Fe^{2+} \rightarrow OH^- + OH^- + Fe^{3+}$$

- **Hypochlorous acid:** $HOCl$
  
  $$H_2O_2 \xrightarrow{MPO} HOCl + OH^-$$

**myeloperoxidase = MPO**

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**Chronic Granulomatous Disease of Childhood (CGD):** deficiency of NADPH Oxidase
Nitric Oxide (NO •) Synthase

L-arginine $\rightarrow$ NO • $\rightarrow$ hydroxyl radical peroxynitrites

- Endothelial cell
- Macrophages (inducible): intracellular cytotoxic agent
- Nervous system
Oxidant Targets

a) unsaturated lipids: lipid peroxidation
   \[ \text{LOOH} = \text{lipid hydroperoxides} \]

c) proteins
   - sulfhydryl groups
   - methionine
   - tyrosine

d) nucleic acids
Degranulation

- **Bactericidal proteins** (e.g. defensins)
- **Proteases**
  - serine proteases (e.g. elastase)
  - metalloproteinases (e.g. collagenase, gelatinase)
- **Acid hydrolases**
Oxidants
Proteases

Anti-oxidants
Anti-proteases
Protective Mechanisms

Anti-oxidant: specific vs. non-specific

Specific enzymes:

Superoxide dismutase: \(2\text{O}_2^- + 2\text{H}^+ \rightarrow \text{H}_2\text{O}_2 + \text{O}_2\)

Catalase: \(2\text{H}_2\text{O}_2 \rightarrow 2\text{H}_2\text{O} + \text{O}_2\)

Glutathione peroxidase: \(\text{H}_2\text{O}_2 + 2\text{GSH} \rightarrow 2\text{H}_2\text{O} + \text{GSSG}\)
\(\text{LOOH} + 2\text{GSH} \rightarrow \text{H}_2\text{O} + \text{LOH} + \text{GSSG}\)

LOOH = lipid hydroperoxides
GSH = reduced glutathione
GSSG = oxidized glutathione
Non-specific scavengers:

- Vitamin E
- Vitamin C
- Beta-carotene
Anti-proteases

• α-1- anti-protease (anti-trypsin):
  – plasma protein
  – binds proteases including elastase
  – inactivated by oxidants

• α-2- macroglobulin
  – plasma protein
  – binds proteases

• TIMPs: tissue inhibitors of metalloproteinases
  – cell derived
Synergism: Inactivation of alpha-1-Anti-trypsin

1. HOCl Dependent

PMNs → HOCl → a-1-antitrypsin (active) → a-1-antitrypsin (inactive)

2. Metalloproteinase Dependent

PMNs → Metalloproteinase (collagenase) → a-1-antitrypsin (active) → a-1-antitrypsin (inactive)
Case: A 3 year old boy is brought to the 
emergency department

- **CC:** a productive cough, fever (temp 102.1 C), and headache.
- **PEx:** healthy boy with rales present on auscultation of the left lower chest.
- **CxR:** intra-alveolar infiltrate in the left lower lobe.
- **Hx:** mother reports multiple episodes (approx. 5 per year) of recurrent bacterial infections including otitis media, sinusitis, pneumonia, and purulent skin lesions. These infections usually responded to antibiotic treatment.
List three different mechanisms that could account for this patient's increased susceptibility to bacterial infection:

1. 

2. 

3. 
Neutrophil Recruitment

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inflammatory mediators (e.g. IL-8, C5a)

Tissue Injury (e.g. Bacterial infection)

- phagocytosis
- oxidant production
- lysosomal granules
Different mechanisms that could account for this patients increased susceptibility to bacterial infection:

1. Lack of neutrophils: leukopenia
2. Defective neutrophil function
   - Adhesion / migration
   - Phagocytosis
   - Bacterial killing
3. Lack of chemoattractants: deficiency
4. Lack of opsoninization of bacteria
   - antibody deficiency / complement def.
Additional References:

**Phagocytic Cells:**
Parham, The Immune System (2nd ed.): pgs. 15-17, 202-209.