M1 - Immunology, Winter 2008

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Arachidonic Acid Metabolites and Inflammation

Joseph Fantone, M.D.
Host Defense 2/12  10-11:00am
INFLAMMATORY MEDIATORS

PLASMA DERIVED
- COMPLEMENT CASCADE
  C3a, C5a
- COAGULATION CASCADE
  Thrombin, plasmin

CELL-DERIVED
- VASOACTIVE AMINES
  histamine, serotonin
- OXYGEN METABOLITES
  hydrogen peroxide (H2O2)
  superoxide anion (O2⁻)
  hypochlorous acid (HOCl⁻)
- ARACHIDONIC ACID METABOLITES
  cyclooxygenase-derived
  lipoxygenase-derived
- CYTOKINES
  Interleukins
  Chemokines
  Interferons
  Tumor Necrosis Factor
  Growth Factors
Intended Learning Outcomes: To Understand The

• Primary inflammatory mediators derived from the metabolism of arachidonic acid including their primary cellular source and biological activity.

• Effects of nonsteroidal anti-inflammatory compounds on blocking the production of arachidonic acid metabolites during disease

• Mechanism of aspirin therapy and diets rich in fish containing high levels of omega 3 fatty acids as potentially important in lowering the incidence of cardiovascular disease.
YOU ARE WHAT YOU EAT
Arachidonic acid - CH
CH₂-O-P̵O̵R

Phospholipid

Phospholipase A

CH₂O

HO-CH
CH₂-O-P̵O̵R
Lysophospholipid

+ Arachidonic acid

Arachidonic acid - CH
CH₂-O-P̵O̵R

Diacylglycerol

Phospholipase C

CH₂O

HO-CH
CH₂-O-P̵O̵R

Arachidonic acid + HO-CH
CH₂-O-P̵O̵R

Diacylglyceride lipase

Cyclooxygenase 1 + Lipooxygenase Products
Cyclooxygenase 2
Stimuli

Cell Membrane Phospholipids

↓ PHOSPHOLIPASE A2

LIP OXYGENASE PATHWAY

HETES [mono & di]

+ LEUKOTRIENE [SRS-A]

Arachidonic Acid

↓ CYCLOOXYGENASE

PGG₂ - PGH₂

↓

PGI₂ UNSTABLE

↓

PGE₂

↓

TXA₂ UNSTABLE

↓

TXB₂

↓

6-Keto PGF₁α
Leukotriene Synthesis

1. Arachidonic Acid
   \[ \xrightarrow{\text{Lipoxygenase}} \]
   \[ \xrightarrow{} \]
   5-HPETE

2. Leukotriene A (LTA)
   \[ \xrightarrow{\text{Glutathione-S-transferase}} \]
   \[ \xrightarrow{} \]
   Leukotriene B (LTB)

3. Leukotriene C (LTC)
   \[ \xrightarrow{\text{Glutathione-S-transferase}} \]
   \[ \xrightarrow{} \]
   Leukotriene D (LTD)
<table>
<thead>
<tr>
<th>CELL</th>
<th>PRODUCT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Neutrophils</td>
<td>Leukotrienes</td>
</tr>
<tr>
<td>Macrophage/Monocyte</td>
<td>Prostaglandins + Leukotrienes</td>
</tr>
<tr>
<td>Platelets</td>
<td>Thromboxoxane</td>
</tr>
<tr>
<td>Endothelial Cells</td>
<td>Prostacyclin</td>
</tr>
</tbody>
</table>
# Biological Function

## Cyclooxygenase-derived Products:

<table>
<thead>
<tr>
<th>Product</th>
<th>Function</th>
</tr>
</thead>
<tbody>
<tr>
<td>Prostaglandin E&lt;sub&gt;2&lt;/sub&gt;/Prostacyclin</td>
<td>Immunoregulatory</td>
</tr>
<tr>
<td></td>
<td>• Inhibits Immune cell activation</td>
</tr>
<tr>
<td></td>
<td>• Inhibits cytokine production</td>
</tr>
<tr>
<td></td>
<td>• Inhibits mast cell activation</td>
</tr>
<tr>
<td></td>
<td>Blocks platelet aggregation</td>
</tr>
<tr>
<td></td>
<td>Increases vasodilation</td>
</tr>
<tr>
<td></td>
<td>Stimulates adenylate cyclase</td>
</tr>
<tr>
<td>Thromboxoxane</td>
<td>Causes vasoconstriction</td>
</tr>
<tr>
<td></td>
<td>Induces platelet aggregation</td>
</tr>
</tbody>
</table>
Biological Function

Lipoxygenase-derived Products:

Leukotriene $\text{B}_4$  Neutrophil Activation  
- degranulation

Mast cell activation  
- degranulation

Leukotriene $\text{C,D,E}$ (SRS-A)  Causes smooth muscle contraction  
Increases vascular permeability
In Vivo Effects of Arachidonic Acid Derived Products

• Regulates Thermostatic Set Point (Fever)
• Regulates Pain (Interacts with pain receptors)
• Regulates Blood Flow
• Regulates Leukocyte Activity
Hypothalamus

Production of Fever

Viruses
Bacteria
Toxins

Phagocytic
leukocytes

Activated
leukocytes
Endogenous
pyrogen

Arachidonic
Acid

Prostaglandin E2

Temperature

(e.g. Interleukin-1)

Aspirin
NSAIDs

Shivering
Sweating
Vasomotor tone
Rheumatoid Arthritis distorts joints

Source: http://www.nih.gov/
Immunopathology of Rheumatoid Arthritis

- Complement
- Antigen
- Altered IgG
- Chemotaxis
- Fixation
- Activation
- Lysosomal Enzymes
- Collagenase
- Neutral Proteases
- Phospholipase
- Cartilage
- Arachidonic acid
- Nonsteroidal Anti-inflammatory Agents
- Prostaglandins
- Nerve Sensitization
- Vasodilation

Source: Undetermined
Chemotactic Activity of LTB4

BY: Greg Luerman

GNU 1.2

Pharmacologic Regulation of Arachidonic Acid-Derived Products

• Modulate Phospholipase activity:
  – Suppress the release of arachidonic acid (no substrate available)
  – Blocks both COX and LO-derived products

• Modulate Cyclooxygenase Activity:
  – Blocks Cyclooxygenase-derived products
  – COX-1 and COX-2 inhibitors

• Modulate specific enzymes down-stream from COX:
  – Thromboxane synthetase inhibitors

• Modulate lipoxygenase activity:
  – Block 5-lipoxygenase enzyme
  – Small molecule receptor antagonists for cysteiny1 leukotrienes
Non-Steroidal Anti-Inflammatory Compounds

- Aspirin (acetysalicylic acid)
- Ibuprofen (propionic acid derivatives)
- Indomethacin (indole derivatives)
- Tylenol (Acetaminophen)
- COX-2 Inhibitors (Vioxx, celebrex, Bextra)
COX-2 Inhibitors

- **CELEBREX** (Celecoxib) Pfizer-(Pharmacia)
- **BEXTRA** (Valdecoxib) Pfizer
- **VIOXX** (Rofecoxib) Merck

- Osteoarthritis
- Rheumatoid arthritis
- Primary dysmenorrhea
- Pain management
- Complications!!
INHIBITS CYCLO-OXYGENASE ENZYME IRREVERSIBLY BY ACETYLATING THE ENZYME AT THE ACTIVE SITE, THUS THE PRODUCTION OF ENDOPEROXIDES AND THEIR DERIVATIVES, INCLUDING PROSTAGLANDINS, THROMBOXANES, AND PROSTACYCLINS WILL BE INHIBITED.
INDOMETHACIN

IBUPROFEN

BOTH INHIBIT CYCLO-OXYGENASE ACTIVITY BY BINDING REVERSIBLY TO THE ACTIVE SITE OF THE ENZYME, THUS BLOCKING THE FORMATION OF PROSTAGLANDINS, THROMBOXANES, AND PROSTACYCLINS.
AN ASPIRIN A DAY

Roughly 80 million aspirin tablets are consumed daily in the USA
Of those:
  72% are taken for disease prevention
  28% are taken for pain
Reduce the risk of heart attack or stroke with……

Aspirin

BY: Chaval Btasil

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THE HOMEOSTATIC BALANCE

PGI$_2$
ENDOTHELUM

TXA$_2$
PLATELETS
Thrombus Formation

- Elastic Lamina
- Basement Membrane
- Endothelium
- Platelets
- Injury
- ADP
- Thromboxane
- Collagen
- Aggregation
- Organization
- Plaque
Can Aspirin Act As An Anti-thrombogenic Agent?

• Inhibits platelet aggregation by blocking platelet-derived thromboxane production

• Blocks platelet cyclooxygenase for the life of the platelet, as no new protein synthesis occurs

• Blocks endothelial cell-derived prostacyclin

• Suppression of endothelial cell-derived prostacyclin is short lived as endothelial cells can generate new cyclooxygenase enzyme

• Platelet activity is blocked more than endothelial cell activity
COX-2 inhibitors work by blocking COX-2 enzyme which is involved in the inflammation pathway. By sparing COX-1 gastrointestinal toxicity is reduced.
lipid mediators of Inflammation

Stimulus

Phospholipase

Phospholipids

Cell membrane

Arachidonic acid
Arachidonic acid

Cell membrane
Phospholipids

Stimulus

Phospholipase

Arachidonic acid

COX-1+2
Prostaglandins
Prostaglandin E$_2$
Prostacyclin PGI$_2$

COX-1
Thromboxanases
TXB$_2$

Lipooxygenases (5-LO)
Leukotrienes

LTB$_4$
LTC$_4$, LTD$_4$
Acute inflammation: lipid mediators

Stimulus

Phospholipase

Arachidonic acid

Cell membrane
Phospholipids

Prostaglandins
Prostaglandin E₂
Prostacyclin PGI₂

COX-1+2

Thromboxanes
TXB₂

COX-1

Leukotrienes

Lipooxigenases (5-LO)

LTB₄
LTC₄, LTD₄

Vasodilation, Increase vascular permeability, Control platelet aggregation, Chemotaxis, Pain, Fever
Acute inflammation: lipid mediators

An important role in vascular homeostasis

Endothelium

Prostacyclin PGI$_2$

Anti-thrombotic

Pro-thrombotic

Platelets

TXB2
Acute inflammation: lipid mediators

Endothelium

**COX-2**

Prostacyclin $\text{PGI}_2$

Anti-thrombotic

Platelets

**COX-1**

$\text{TXB2}$

Pro-thrombotic

NSAIDs inhibit both COX-1 and COX-2; COXIBs inhibit COX-2
Prostacyclin $\text{PGI}_2$

COX-2

Prostacyclin $\text{PGI}_2$

Anti-thrombotic

COX-1

Thromboxane $\text{TXB}_2$

Pro-thrombotic

Endothelium

Platelets

Therapeutic targets

Ibuprofen*

* Classical NSAID, it inhibits both COX enzymes
Acute inflammation: lipid mediators

Therapeutic targets

Endothelium

COX-2

Prostacyclin PGI$_2$

Anti-thrombotic

Platelets

COX-1

TXB2

Pro-thrombotic

Vioxx®
Acute inflammation: lipid mediators

Therapeutic targets

Endothelium

Aspirin
inhibits COX-2 irreversibly

Prostacyclin PGI₂

TXB2

Platelets

Aspirin
inhibits COX-1 irreversibly

All cells but the platelet can resynthesize the enzymes

Anti-thrombotic

Pro-thrombotic
INFLAMMATORY MEDIATORS

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  Tumor Necrosis Factor
  Growth Factors