MUCOSAL IMMUNITY

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- CHALLENGES FACED BY THE MUCOSAL SYSTEM
- SPECIALIZATION OF CELLS INVOLVED IN MUCOSAL IMMUNITY
- ORGANIZATION OF THE MUCOSAL IMMUNE SYSTEM
- CLINICAL IMPLICATIONS
DEFINITIONS

MALT = MUCOSA-ASSOCIATED LYMPHOID TISSUE

MALT is the highly specialized immune system which protects mucosal surfaces. The lymphoid elements associated with different mucosal sites share organizational as well as functional similarities. It is the largest mammalian lymphoid organ system and in an adult it comprises approximately 80% of all lymphocytes.
COMPONENTS OF THE MUCOSA-ASSOCIATED LYMPHOID TISSUE

- Gastrointestinal tract (GALT)
- Bronchial Tree (BALT)
- Nasopharyngeal area (NALT)
- Mammary gland
- Salivary and lacrimal glands
- Genitourinary organs
- Inner ear

THE CHALLENGES

- Most frequent portal of entry for harmful substances. Thus the MALT has to mount an effective response against a vast number of potential pathogens.

- The mucosal membranes of the digestive tract must allow for the absorption of nutrients by the host. Thus the MALT must remain hyporesponsive to an entire array of harmless substances.
SPECIALIZED COMPONENTS OF MALT

B CELLS

- Humoral responses are central to an effective mucosal immunity.
- The main humoral mediators of specific mucosal immunity are secretory IgA and, to a lesser extent, secretory IgM.
- The normal intestinal mucosa contains at least 20 times more IgA+ than IgG+ lymphocytes.
CRITICAL FEATURES OF SECRETORY IgA

- Resistance against common intestinal proteases
- Inability to interact with complement or cells in a way to cause inflammation

MECHANISMS OF PROTECTION BY SIgA AT MUCOSAL SURFACES

- Inhibition of adherence
- Virus neutralization
- Neutralization of enzymes and toxins
- Immune exclusion and inhibition of antigen absorption
FACTORS CONTROLLING IgA ISOTYPE SWITCHING

- APC
- B7
- CD28
- MHC II
- TCR
- CD4
- CD40
- CD40L
- B
- ACTIVATION ISOTYPE SWITCHING
- PROLIFERATION DIFFERENTIATION
- IgA-J
- IL-2/IL-4
- IL-5
- IL-6
- IL-10
- TGF-β
- IL-2
- IL-4

FACTORS CONTROLLING THE SECRETION OF IgA: THE J CHAIN

- THE J CHAIN IS A 15 KD POLYPEPTIDE THAT IS DISULFIDE-BONDED TO THE TAIL-PIECES OF BOTH IgM AND IgA
- IgA SECRETING B CELLS IN THE BONE MARROW DO NOT EXPRESS THE J CHAIN AND THUS SECRETE IgA MONOMERS
- THE MAJORITY OF IgA PRODUCING B CELLS IN THE MUCOSA EXPRESS THE J CHAIN AND THUS PRODUCE DIMERIC IgA
- THE J CHAIN STABILIZES THE MULTIMERS AND IT APPEARS TO DETERMINE THE POLYMERIC IgA AND IgM STRUCTURE WHICH ALLOWS POLYMERIC Igs TO COMPLEX WITH THE SECRETORY COMPONENT
FACTORS CONTROLLING THE SECRETION OF IgA: THE SECRETORY PIECE (POLYMERIC Ig RECEPTOR)

<table>
<thead>
<tr>
<th>LAMINA PROPRIA</th>
<th>MUCOSAL EPITHELIAL CELL</th>
<th>LUMEN</th>
</tr>
</thead>
<tbody>
<tr>
<td>DIMERIC IgA</td>
<td>SECRETORY COMPONENT WITH BOUND IgA</td>
<td>ENDOCYTOSED COMPLEX OF IgA AND SECRETORY COMPONENT</td>
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<tr>
<td>IgA-J</td>
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SECRETED IgA

PROTEOLYTIC CLEAVAGE

T CELLS
TH1 OR TH2?

<table>
<thead>
<tr>
<th>MUCOSAL TISSUES</th>
<th>% CD3⁺</th>
<th>TCR</th>
<th>%CD4⁺</th>
<th>TH1:TH2</th>
<th>CD4:CD8</th>
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<tr>
<td></td>
<td></td>
<td>αβ</td>
<td>γδ</td>
<td></td>
<td></td>
</tr>
<tr>
<td>INDUCTIVE SITES</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PEYER’S PATCHES</td>
<td>25-35</td>
<td>&gt;90</td>
<td>1.5</td>
<td>60</td>
<td>1:1</td>
</tr>
<tr>
<td>EFECTOR SITES</td>
<td></td>
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<td></td>
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<td></td>
</tr>
<tr>
<td>LAMINA PROPRIA</td>
<td>40-60</td>
<td>&gt;95</td>
<td>1.5</td>
<td>60</td>
<td>1:2-3</td>
</tr>
<tr>
<td>INTRAEPITHELIUM</td>
<td>80-90</td>
<td>35-45</td>
<td>45-65</td>
<td>5-10</td>
<td>1:1</td>
</tr>
</tbody>
</table>

LAMINA PROPRIA LYMPHOCYTES

- LYMPHOCYTES WHICH ARE SCATTERED DIFFUSELY THROUGHOUT THE LAMINA PROPRIA OF THE INTESTINE. (LAMINA PROPRIA=LAYER OF CONNECTIVE TISSUE BETWEEN THE EPITHELIUM AND THE MUSCULARIS MUCOSA)
INTRAEPITHELIAL LYMPHOCYTES (IELs)

- IELs are lymphocytes which are interspersed between the columnar epithelial cells of the villi in the small and large intestine.
- In humans, most of the IELs are CD8+ T cells. Approximately 10% of IELs are γδ cells.
- Both the γδ and the αβ TCR+ IELs show limited diversity of T cell.
- IELs express a novel integrin termed HML-1 (human mucosal antigen 1).

FUNCTIONAL PROPERTIES OF IELs.

- First immune cell line of defense in the intestine.
- Display cytotoxic activity.
- Secrete large amounts of cytokines especially IFN-γ and TNF-α.
- Modulate the kinetics of epithelial cell renewal.
- Play a regulatory role in tolerance to dietary antigens.
**ORAL TOLERANCE**

- ORAL ADMINISTRATION OF A PROTEIN ANTIGEN MAY LEAD TO SUPPRESSION OF SYSTEMIC HUMORAL AND CELL-MEDIATED IMMUNE RESPONSES TO IMMUNIZATION WITH THE SAME ANTIGEN.

- POSSIBLE MECHANISMS:
  - INDUCTION OF ANERGY OF ANTIGEN-SPECIFIC T CELLS
  - CLONAL DELETION OF ANTIGEN-SPECIFIC T CELLS
  - SELECTIVE EXPANSION OF CELLS PRODUCING IMMUNOSUPPRESSIVE CYTOKINES (IL-4, IL-10, TGF-β)
REGULATORY T CELLS
(CD4+)

- TH3 CELLS: A POPULATION OF CD4+ T CELLS THAT PRODUCE TGF-β. ISOLATED FROM MICE FED LOW DOSE OF ANTIGEN FOR TOLERANCE INDUCTION
- TR1 CELLS: A POPULATION OF CD4+ T CELLS THAT PRODUCE IL-10. CAN PRODUCE SUPPRESSION OF EXPERIMENTAL COLITIS IN MICE
- CD4+CD25+ REGULATORY T CELLS: A POPULATION OF CD4+ T CELLS THAT CAN PREVENT AUTO REACTIVITY IN VIVO.

REGULATORY T CELLS

- CD8+ SUPPRESSOR T CELLS: THE FIRST IDENTIFIED POPULATION OF REGULATORY T CELLS THOUGHT TO BE INVOLVED IN ORAL TOLERANCE. THEIR FUNCTIONS AND CHARACTERISTIC HAVE NOT BEEN CLEARLY DEFINED
- γδ T CELLS: STUDIES IN MICE INDICATE THAT THEY HAVE AN IMPORTANT ROLE IN SOME MODELS OF ORAL TOLERANCE.
EPITHELIAL CELLS

Scanning electron microscopy of a single microdissected dome (a) of a murine Peyer's patch. The M cells are identified by their relatively short, dark brush border; they are restricted to the dome epithelium (upper half in b). Crypts (arrows) are opening to the cleft between the dome and the neighboring villi.

From: Gebert et al., Am. J. Pathol. 154:1573, 1999
CHARACTERISTICS OF M CELLS

- M ("membrane-like") CELLS ARE SPECIALIZED EPITHELIAL CELLS WHICH OVERLIE LYMPHOID FOLLICLES DOMES ALONG THE LENGTH OF THE SMALL AND LARGE INTESTINE.
- STRUCTURAL FEATURES INCLUDE:
  - FEW SHORT IRREGULAR MICROVILLI
  - ABUNDANT ENDOCYTIC VESICLES
  - LOW LYSOSOMAL CONTENT
  - DISTINCTIVE GLYCOCALIX
  - BINDING SITES FOR SECRETORY IgA BUT NO SC
  - POCKETS IN THE BASOLATERAL SURFACE

FUNCTIONS OF M CELLS

- ANTIGEN SAMPLING
- PORTAL OF ENTRY FOR SELECTED PATHOGENS
Dendritic cell-mediated transport of commensal bacteria in the gut

Dendritic cells can sample antigen indirectly via M-cell transcytosis (right) or directly via processes that extend across the epithelial barrier (left). DCs present antigen to B- and T-cells, either directly within the lamina propria or following trafficking to the regional lymph nodes.

From: Kraehenbuhl and Corbett, Science 303:1624, 2004

Role of CX$_3$CR1 in Luminal Sampling by Gut DCs

CX3CR1 is a chemokine receptor whose ligand is an unusual chemokine; rather than secreted, it is membrane-bound.

From: Niess et al. Science 307:254, 2005
ORGANIZATION OF MALT

PEYER’S PATCHES

- ORGANIZED MUCOSAL LYMPHOID FOLLICLES WHICH LACK AFFERENT LYMPHATICS.
- PEYER’S PATCHES ARE FOUND IN THE SMALL INTESTINE.
- FOLLICLES SIMILAR TO PEYER’S PATCHES ARE FOUND IN THE APPENDIX, IN THE REST OF THE GASTROINTESTINAL TRACT AND IN THE RESPIRATORY TRACT.
Anatomy of a Peyer’s Patch


INDUCTIVE LYMPHOEPITHELIAL TISSUES: PEYER’S PATCHES
Effector Sites:
Lamina Propria and Intraepithelium

Clinical Implications
**IgA DEFICIENCY**

- IT IS THE MOST COMMON PRIMARY IMMUNODEFICIENCY
- IT IS USUALLY DEFINED BY A SERUM IgA CONCENTRATION OF LESS THAN 50 µg/ml
- IgA DEFICIENT INDIVIDUALS OFTEN APPEAR PERFECTLY HEALTHY AND ARE IDENTIFIED
  - UPON SERVING AS BLOOD DONORS
  - UPON UNDERGOING ANAPHYLACTIC SHOCK WHEN RECEIVING BLOOD TRANSFUSIONS

**CLINICAL MANIFESTATIONS OF IgA DEFICIENCY**

- INCREASED INCIDENCE OF INFECTIONS
  - UPPER AND LOWER RESPIRATORY TRACT
  - GASTROINTESTINAL
- HIGHER INCIDENCE OF AUTOIMMUNE DISEASES
- HIGHER INCIDENCE OF ALLERGIC DISEASES
- HIGHER INCIDENCE OF CELIAC DISEASE
INFLAMMATORY BOWEL DISEASE (IBD)

- IBD IS A CHRONIC, RELAPSING AND REMITTING INFLAMMATORY CONDITION

- TWO OVERLAPPING PHENOTYPES:
  - CROHN'S DISEASE (CD), WHICH AFFECTS THE DISTAL SMALL INTESTINE AS WELL AS THE COLON IN A TRANSMURAL MANNER
  - ULCERATIVE COLITIS (UC), WHICH PREDOMINANTLY AFFECTS THE COLON IN A SUPERFICIAL MANNER

- THE ETIOLOGY IS UNKNOWN: DUE TO A DYSREGULATED MUCOSAL IMMUNE RESPONSE TO UNKNOWN ANTIGENS PRESENT IN THE NORMAL, INDIGENOUS BACTERIAL FLORA
  - MUTATIONS IN NOD2 (A CYTOSOLIC RECEPTOR FOR PATHOGENIC BACTERIAL SIGNALS) INCREASE THE RISK OF CD BY A FACTOR OF 20-40.
IBD: IMMUNOLOGIC FEATURES

- CELL-MEDIATED IMMUNITY (ACTIVE CD):
  - INCREASED NUMBER OF ACTIVATED MUCOSAL T CELLS SECRETING IFN-γ (TH1)
  - INCREASED MUCOSAL PRODUCTION OF CYTOKINES THAT ACTIVATE TH1 CELLS (IL-12 AND IL-18)
  - DEFECTS IN REGULATORY (IL-10 PRODUCING) T CELLS

- HUMORAL IMMUNITY: MASSIVE INCREASE IN THE NUMBER OF PLASMA CELLS AND IN IgG PRODUCTION (IgG2 IN CD AND IgG1 IN UC)

- IMBALANCE OF PRO-INFLAMMATORY (TNF-α, IL-1, IL-8, IL-12) AND ANTI-INFLAMMATORY CYTOKINES (IL-10, IL-4, IL-13)
**IBD: EMERGING BIOLOGIC THERAPIES**

- **INHIBITORS OF PROINFLAMMATORY CYTOKINES**
  - Anti-TNF therapies: infliximab

- **ANTI-INFLAMMATORY CYTOKINES**
  - IL-10
  - IL-11

- **ANTI-LEUKOCYTE ADHESION THERAPIES**
  - Anti-α4 integrin: Natalizumab?

- **INHIBITORS OF TH1 POLARIZATION**
  - Anti-IL-12
  - Anti-IL-18
  - Anti-IFN-γ

**CELIAC DISEASE**

- **CELIAC DISEASE IS A T CELL MEDIATED IMMUNE DISEASE OF THE SMALL INTESTINE TRIGGERED BY GLUTEN**

- **MAJOR FEATURES:**
  - VILLOUS ATROPHY WITH A LYMPHOCYTIC INFILTRATE
  - INCREASED EPITHELIAL PROLIFERATION WITH CRYPT HYPERPLASIA
  - MALABSORPTION
CELIAC DISEASE: IMMUNOLOGIC FEATURES

- **ANTIGEN:** GLUTEN (gliadin and glutenins)

- **IT IS ASSOCIATED WITH HLA-DQ2 OR HLA-DQ8 RESTRICTED LAMINA PROPRIA CD4+ T CELLS THAT RECOGNIZE GLUTEN AND SECRETE INTERFERON γ (98% OF PEOPLE WILL CARRY THESE HAPLOTYPES)**

- **GLIADIN IS A SUBSTRATE OF TISSUE TRANSGLUTAMINASE (TRANSFORMS POSITIVELY CHARGED GLUTAMINES TO NEGATIVELY CHARGED GLUTAMIC ACID)**

- **INCREASED B CELL ACTIVITY**
  - ANTIBODIES AGAINST GLIADIN (IgA-AGA, IgG-AGA)
  - ENDOMYSIAL ANTIBODY (IgA-EMA)
  - TISSUE TRASGLUTAMINASE (IgA-tTG)
**CELIAC DISEASE: IMMUNOLOGIC FEATURES**

- **IMPORTANTLY THE HALLMARK OF CELIAC DISEASE IS INTRAEPITHELIAL INFILTRATION BY CD8+ T CELLS**
  - DIFFERENT FROM IBD
  - IELs ARE BELIEVED TO PARTICIPATE IN THE PATHOGENESIS OF CELIAC DISEASE BY MEDIATING THE DESTRUCTION OF THE EPITHELIUM
  - RECENT EVIDENCE POINTS TO THE FOLLOWING SCENARIO:
    - GLUTEN ALTERS EPITHELIAL CELLS OF PATIENTS WITH CELIAC DISEASE LEADING TO PRODUCTION OF IL-15 AND TO THE EXPRESSION OF NON-CLASSICAL MHC CLASS I MOLECULES. IL-15 IN TURN LEADS TO THE EXPRESSION OF RECEPTORS ON IELS FOR THESE NON-CLASSICAL MHC MOLECULES AND TO THE ACTIVATION OF THE IELS, WHICH THEN KILL THE EPITHELIAL CELL
The CD8 side of the story

MUCOSAL IMMUNIZATION
MUCOSAL VACCINES

- Vaccines against mucosal infections must stimulate the MALT in order to be efficacious.

- Because of subcompartmentalization within the MALT, vaccines must be administered by the appropriate route.

- Nonreplicating antigens are often relatively inefficient in yielding strong and long-lasting mucosal antibody responses.

NEW STRATEGIES FOR ANTIGEN DELIVERY:

- Live attenuated recombinant bacteria and viruses with known mucosal tropism.
- Protective vehicles, e.g. liposomes and biodegradable microspheres.
- Mucosal lectin-like molecules endowed with immunostimulatory properties, e.g. cholera toxin.
MUCOSAL IMMUNOTHERAPY

- Strategy to attempt to treat illnesses resulting from immune reactions against autoantigens encountered in nonmucosal tissues.
- Human trials have been conducted in multiple sclerosis, rheumatoid arthritis, uveoretinitis, and type I diabetes.

<table>
<thead>
<tr>
<th>Disease</th>
<th>Oral antigen</th>
<th>Dose</th>
<th>Prophylactic or therapeutic</th>
<th>Outcome</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>Food allergy</td>
<td>Allergen</td>
<td>Increasing dose over time</td>
<td>Therapeutic</td>
<td>About 80% of patients are successfully desensitized</td>
<td>130</td>
</tr>
<tr>
<td>Autoimmune inotaxis</td>
<td>Sequestrated retinal antigens, HLA-B27 + DQ</td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Retinal S-antigen, soluble retinal antigens</td>
<td>4 mg capsule: 3 times a week for 12 weeks</td>
<td>Therapeutic</td>
<td>Marginal clinical benefit; all patients relapsed after cessation of treatment</td>
<td>131, 132</td>
<td></td>
</tr>
<tr>
<td></td>
<td>0.01 mg 5-antigen or 0.05 mg soluble retinal antigens</td>
<td>Therapeutic</td>
<td>No benefit; with possible exacerbation of disease in patients receiving a mixture of soluble retinal antigens</td>
<td>133</td>
<td></td>
</tr>
<tr>
<td>Rheumatoid arthritis</td>
<td>Collagen</td>
<td>0.1 mg bovine type II collagen daily for 1 month, followed by 0.05 mg daily for 6 months</td>
<td>Therapeutic</td>
<td>No benefit</td>
<td>135</td>
</tr>
<tr>
<td></td>
<td></td>
<td>20, 100, 500 or 2,000 µg chicken type II collagen daily for 24 weeks</td>
<td>Therapeutic</td>
<td>Clinically significant response at 20 µg dose</td>
<td>136</td>
</tr>
<tr>
<td></td>
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<td>0.05, 0.5 or 1 mg bovine type II collagen daily for 6 months</td>
<td>Therapeutic</td>
<td>Response at 0.5 mg</td>
<td>137</td>
</tr>
<tr>
<td></td>
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<td>0.5 mg bovine type II collagen daily for 3 months</td>
<td>Therapeutic</td>
<td>Response at 0.5 mg</td>
<td>138</td>
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<tr>
<td></td>
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<td>0.1 mg chicken type II collagen daily for 1 month, followed by 0.5 mg for 2 months</td>
<td>Therapeutic</td>
<td>Improvement in most clinical measures; 4 of 28 patients had complete remission</td>
<td>139</td>
</tr>
<tr>
<td>Type 1 diabetes</td>
<td>Insulin</td>
<td>7.5 mg insulin</td>
<td>Prophylactic</td>
<td>No benefit</td>
<td>140</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2.5 mg or 7.5 mg insulin</td>
<td>Therapeutic</td>
<td>No benefit</td>
<td>140</td>
</tr>
</tbody>
</table>

*For human studies, see National Institutes of Health website for further information. In contrast to experimental animal models, most human clinical trials have attempted to induce and balance the onset of disease (therapeutically). Treatments are prophylactic. This regimen of oral leading to tolerance prior to the onset of clinical disease, whereas they are therapeutic if oral tolerance is induced after the onset of clinical disease. HLA-B27, HLA-B7 haplotypes.
MUCOSAL IMMUNOTHERAPY

- POTENTIAL PROBLEMS:
  - LIMITED SUCCESS IN SUPPRESSING THE EXPRESSION OF AN ALREADY ESTABLISHED IMMUNE RESPONSE
  - MASSIVE AMOUNTS OF TOLEROGENS ARE REQUIRED
  - IMMUNOSUPPRESSIVE EFFECT IS OF SHORT DURATION