Required reading: Owens; Immunology (7TH Edition)
Chapter 1 – Overview of the Immune System: A Historical Perspective of Immunity
Objectives

1. To gain a historical perspective of seminal research that provided underpinnings of immunology discipline.

2. To introduce key concepts of tumor immunology.
Assigned Reading


Historical Paradigms in General Immunology and Tumor Immunology

500 B.C.  1700s-1800s A.D.  2000 A.D.

Recognition of Active Immunity/
Protection from Infectious Agents

Molecular Mechanisms of Immunity
(Ab, cells, cytokines)

Tumor Immunity
Survival of Species Depends on Defense Mechanisms

- Fight/flight
- Barriers - skin
- Immune response-complexity depends on organism

**Vertebrates:**
- Organized lymphoid organs (spleen, thymus, bone marrow, lymph nodes, Peyer’s patches)
- Complex circulatory system (lymphocyte trafficking)
Immunity (Latin)-*immunis*
Legal term = *free from tax burden*

General Properties of Immune Response:

*Protect, defend organism from infectious agents*
- Innate immunity (NK, PMN, MØ, megakaryocytes)
  - Primitive, higher organism
- Adaptive immunity (B, T cells)
  - Only vertebrates

*Recognize self from non-self*
- Primitive and higher organisms (Wilson 1907)
Nonaggressive Incompatibility Reaction in Sponges
(Wilson 1907)

A mixture of dissociated cells obtained from two different species of sponge sorts itself out, and the cells aggregate to form parental body types. (Simplified and highly schematic)
Early Observations of Immunity (epidemics)

- Examples of people resistant, protected from disease
- Attempts to actively induce immunity
"Yet still the ones who felt most pity for the sick and the dying were those who had had the plague themselves and had recovered from it. They knew what it was like and at the same time felt themselves to be safe, for no one caught the disease twice, or, if he did, the second attack was never fatal. Such people were congratulated on all sides, and they themselves were so elated at the time of their recovery that they fondly imagined that they could never die of any other disease in the future."
Significance of Thucydides’ Recognition of Fundamental Concepts of Immune Response

1. Exposure to disease could result in subsequent immunity (*memory*)

2. Protection to one disease did not confer general protection (*specificity*)
Hallmark Characteristics of the Immune Response

- Specificity (distinguish subtle differences in Ag)
- Immunologic memory (recall response)
- Discrimination of self/non-self
- Diversity (discriminate $10^9$ distinct Ag determinants)
- Self-regulation (positive and negative control)
Smallpox

- Earliest disease clinically identified
- Numerous epidemics (1st evidence on faces of Egyptian mummies - 1570 - 1085 BC)
- Led to first defined immunology experiments
Smallpox Etiology

- Inhaled smallpox virus infects epithelial cells lining the trachea.
- Virus spreads via blood to skin epithelium.
- Smallpox lesions occur on the face, body.

★ 40% Mortality rate (affects children, young adults)
Early Attempts to Actively Induce Protection Against Smallpox

- Ancient Chinese dried postules, children inhale through nostril using silver tube (left - male, right - female (B.C.))

- Colonies - Cotton Mather (1660s - 1720s)
  
  *Native Indians, George Washington*
Mary Pierrepont Montagu credited with bringing first awareness of “variolation” process to England

Described method in Turkey to variolate healthy individuals using postules from less ill patients.

Variola (Latin) = smallpox
Variolation = artificial exposure to smallpox
“I am going to tell you a thing that I am sure will make you wish yourself here. The small-pox, so fatal, and so general amongst us, is here entirely harmless by the invention of ingrafting. I am patriot enough to take pains to bring this useful invention into fashion in England and I should not fail to write to some of our doctors very particularly about it, if I knew any one of them that I thought had virtue enough to destroy such a considerable branch of their revenue for the good of mankind!”
Result of Lady Montagu’s efforts in England

Prince & Princess of Whales (& children) were variolated in 1722

Widespread Variolation for Smallpox

★ Danger - high risk of contracting disease (use viable virus to variolate)
Edward Jenner performed 1\textsuperscript{st} defined immunological experiment

"An Inquiry into the Causes and Effects of Variola Vaccinæ" (1798)

\textit{Vaccus} (Latin) = cow (vaccination)

Hypothesis: \textit{Pre-exposure to cowpox protects against smallpox infection.}
Why Think?

Why Not Try the Experiment?

John Hunter (teacher of Edward Jenner)

Just Do It!

Nike
“Yours is the comfortable reflection that mankind can never forget that you have lived. Future nations will know by history only that the loathsome smallpox existed.”
Cure for smallpox never found, only protection

- 1966 > 10 million infected/year
- 1966 - 1977 - Initiative to eradicate smallpox by vaccination
• Smallpox is the first infectious disease to be eradicated by worldwide program of vaccination

• Ethical debate over destruction of remaining vials
  • Virulent smallpox too dangerous to keep (germ war-fare)
  • May be necessary to use virus to develop anti-viral reagents (humans only host)
Impact of Jenner Study on Immunology

- Widespread acceptance of method for inducing immunity to infectious diseases. Safer than variolation using smallpox.

- Thought only living organisms could confer immunity (not immediately adaptable to other diseases).

- Protection not passed from generation to generation. Studies not directed toward understanding mechanisms.
Louis Pasteur
‘Father of immunology’

“Chance favors only the prepared mind.”
1878
1. Inoculate with attenuated bacteria: 
   *Animal lives*

2. Challenge with lethal dose cholera toxin: 
   *Animal protected*
Significance of Pasteur’s Findings

Process called *vaccination* in homage to Jenner

- Demonstrated weakened, attenuated bacteria can serve as vaccine
- Safer → concept of prophylactic therapy
- Infectious disease had specific identifiable causative agents
- Field dominated toward isolating infectious agents
Emil von Behring - Landmark Experiment Demonstrating “Anti-toxin” Basis of Immune Response (1898) – Awarded 1st Nobel Prize 1901

Immunize DT (attenuated bacteria)

Remove serum
Adoptively transfer to naïve recipient

Challenge with DT
Resistant to DT, not other infectious agents

Conclusions

- Antitoxin in serum can neutralize toxic effects of infectious agent (DT)
- Specificity - neutralize DT but not other bacterial toxins
Paul Ehrlich Scientific Contributions
Nobel Prize in Immunology - 1908

- Founder of scientific discipline of immunology
- Impact broader than immunology

“The immune substances…..in the manner of magic bullets, seek out the enemy.”
–Paul Ehrlich
Paul Ehrlich

- 1891 – Koch hired Ehrlich at the Institute for Infectious Disease

- Brought together Paul Ehrlich and Emil von Behring who was working on anti-diphtheria serum immunotherapy

- Ehrlich applied quantitative analysis to immunology

Robert Koch
Nobel Prize – 1905
Discovered causative agent and testing methods for tuberculosis, anthrax, cholera, pink eye → revolutionized bacteriology
Limitations of von Behring’s Serum Therapy

- Serum production difficult, yield of serum insufficient
- Failed to standardize the sera so not reproducible
- Ehrlich developed quantitative methods to measure sera activity - “I made it my task to introduce measures and figures into investigations regarding the relations existing between toxine and antitoxine”
  
P Ehrlich, 1900
- Produced huge quantities of standardized serum, provided to pediatric clinics
  
  1895 – German Congress of Internal Medicine – ‘New remedy unequivocally assessed the best treatment every realized’
Paul Ehrlich – Guiding Principles

- Systematic experimentation
- Quantitative, chemical basis of all questions
- Important to test biological responses in vitro & in vivo
Paul Ehrlich – Guiding Principles

- Obsessed with organic chemistry
- Believed in rigorous recording ideas, experiments-developed own orthography
- Daily handed out carbon copies with ideas written on it

The Most Elegant Immunological Experiment of the 19th Century

“I have been able to succeed in finding a simple research plan...” *Paul Ehrlich* 1892

Question: Does antibody in neonates derive from the mother (passive transfer) or father (genetic transfer)?
'It is not to be doubted that the immunity that we have observed in the offspring of immune mothers....depends on the transfer of maternal antibody.' (1892) P Ehrlich
Paul Ehrlich – Side-Chain Theory

- 1\textsuperscript{st} comprehensive theory of antibody formation
  Side-chain theory

- Addresses question of how immune response (anti-toxins) distinguishes so many antigens with such specificity
Emile Fischer – Lock and Key hypothesis for enzyme-substrate interactions

- Nobel Prize in chemistry (1902) for research on sugars, proteins, fats and enzymes
Paul Ehrlich’s Side-chain Theory of Antibody Formation (1897)

- No physical evidence for existence of antibodies
- Innovation of using diagrams to illustrate hypothetical molecules
- New way of thinking about immunology – first coined term ‘antibody’; receptor novel concept.
- Antigens bind to pre-existing cell surface receptors, stimulate cells to synthesize more receptors and to secrete them into the extracellular fluid.
Draft of side chain theory in office of Paul Ehrlich
Humoral (Ab/serum) vs. Cellular Immunity

- New paradigm - reports by Ehrlich, von Behring support concept Ab responsible for immunity, i.e., cells not necessary.

- Next 50 years dominated by study of Immunochemistry (Ab structure, Ab/Ag interactions, cellular source of Ab)

- Study of cellular immunity largely ignored (Metchnikoff)
Immunoglobulin Structure

Variable regions
Durability of Ab Response

- Measles infection on the Faroe Islands in 1781 protected patients from re-infection in 1846 (Panum, 1847).
- Survivors of 1918 influenza pandemic have Ag-specific Ab titers to HA protein in 2008 (Yu, 2008).
- Persistent protective Ab is found in people vaccinated against yellow fever (75 years), smallpox (50 years), and polio (40 years) (Cooney, 1991; Crotty, 2003; Paul, 1951).
- Longitudinal analysis of Ag specific Ab titers in humans calculated $t_{1/2}$ of those Abs against measles to be 3014 yrs (Amanna, 2007).
In a famous experiment, the Russian immunologist Elie Metchnikoff stuck a splinter into a starfish larva (a). The next day the foreign body was surrounded by macrophages (b). Metchnikoff concluded that the body defends itself against foreign particles that threaten its integrity by mobilizing cells of a special type, which attempt to eliminate the foreign matter.
Elie Metchnikoff  
Father of Innate & Cellular Immunity

Cavaillon, J-M, J Leuk Biol 90:413, 2011
Elie Metchnikoff - Host Cells Responsible for Immunity (1893)

- 1st evidence that cells respond to foreign antigens
- Unable to demonstrate specificity
- Revealed basic tenet of inflammation & protective function of recruited leukocytes
- Not until 1940s-1950s that cellular immunology becomes in vogue
1908 – Nobel Prize
In recognition of their work on immunity

Paul Ehrlich and Elie Metchnikoff jointly awarded Nobel Prize for contributions to immunology

Basis of immunological research for next century
- Roswell Park founded 1st institute dedicated to cancer research
- First scientific observations implicating immunological reactions to malignancy (Gaylord, Clowes, Baeslack)
- Dr. G.H.A. Clowes, driven by the fact that his son had leukemia, initiates the first cancer chemotherapy program in the United States
From Ehrlich to Burnet

1900s
Paul Ehrlich

1950s
MacFarlane Burnet
Awarded Nobel Prize for Contributions to Immunology

- Paul Ehrlich – 1908
  100\textsuperscript{th} year anniversary

- Frank MacFarlane Burnet – 1960
  50\textsuperscript{th} anniversary of clonal selection theory (1957)

Unifying theme – specificity of immune response
Inoculate 2×10^6 leukocytes

Opaque foci: cellular proliferation, immune response

Chick chorioallantoic membrane

Conclusions

- Mediated by cellular arm (T cells)
- Self vs. non-self recognition (MHC I-dependent)

Macfarlane Burnet and Peter Medawar

Research in Transplantation/Graft Rejection Mechanisms Advanced by WWII
1960 - Macfarlane Burnet (center) and Peter Medawar (second from right) were awarded the Nobel Prize for the discovery of immunological tolerance.
Abiding Passion-Scientific Work

- Found benchwork an excellent ‘occupational therapy’ that allowed his mind to wander and wonder while his hands were occupied with pipettes and eggs.

- Unexpected results would not be dismissed as technical mistakes.

- Rarely used statistics; biologically important data should be obvious.
Abiding Passion—Scientific Work

- Worked alone
- One or sometimes two graduate students
- Careful in selection of graduate students
- Succession of highly competent and devoted women
First Draft of Clonal Selection Theory

[Handwritten text with scientific content]

[Photograph of scientist at a laboratory bench]
Macfarlane Burnet – 1957
Clonal Selection Theory

- Antigen selects antibody-forming cell by binding to surface receptors
- Proliferation of the selected clone & release of soluble antibody
- Early exposure to antigen (at birth) leads to tolerance
• Immune system recognizes tumor Ag as “foreign” and rejects emerging cancer cells continuously.

• Cancer develops if imbalance between host immune response and tumor environment.

Br Med J, 1:841, 1957
**Principles of Tumor Immunity** *(Gross, 1943)*

- **Chemically/virally induced tumor**
- **Remove tumor**
- **Tumor Challenge**
- **Tumor Rejected**
- **Tumor Growth**

**Conclusions**

- Evidence for tumor rejection antigen
- Specificity of anti-tumor immune response
- Immunologic memory
- Cell mediated response (Subsequently showed T cell dependent; Ab fail to transfer tumor immunity)
Are antibody production & cell-mediated immunity performed by same cell?

*Paul Ehrlich developed staining techniques; identified leukocyte subtypes in blood – basis of hematology
1956 - Glick

Identification of “B cells” as source of Ab

• Surgically remove Bursa of Fabricius in chickens
• Assistant mistakenly used to demonstrate Ab response
• Unable to make Ab, still reject skin graft
Cellular Immunity

1961 - Miller and Good

Identification of “T cells” as mediator of self/non-self recognition

- Thymectomize animals at birth
- Challenge with foreign graft
- Increased survival time of graft
T Cell Mediated Cytotoxicity

- Perforin/cytotoxic granules
- Fas/FasL mediated killing
Cytotoxic T Lymphocytes Attacking Cancer Cell

Lethal holes

Cancer cell

Cytotoxic T cell

www.immatics.com
Cellular Mediators of the Adaptive and Passive Immune Response
- Molecular analysis of B, T cell receptors
- Identification of immunoregulatory cytokines
- Signal transduction pathways underlying B, T activation, cytokine regulation
- Molecular identification of co-stimulatory molecules, adhesion molecules
- Role of professional antigen presenting cells (APC; dendritic cells) in controlling T cell response
- Molecular understanding of host - tumor relationship
Nobel Laureates in Immunology

- Cesar Milstein and Georges F. Kohler (1984) *Development of Technique for Monoclonal Antibody Formation*

- Niels K. Jerne (1984) *Theories concerning the specificity in development (lymphocyte clonality) and control of the immune system*

- Peter Doherty and Rolf Zinkernagel (1996) *Discoveries Concerning the Specificity of the Cell Mediated Immune Defense*

  "It was a wonderful example of how certain things cannot be planned," says Zinkernagel. "Absolutely, this was a miracle of chance."
R. Yalow (1977)
*Development of radioimmunoassays of peptide hormones*

*Discoveries concerning genetically determined structures on the cell surface (major histocompatibility complex) that regulate immunological reactions.*

S. Tonegawa (1987)
*Discovery of the genetic principle for generation of antibody diversity.*

J.E. Murray and E.D. Thomas (1990)
*Discovery concerning organ and cell transplantation in the treatment of human diseases; luck and collaborations critical.*
Nobel Laureates in Immunology

- B. Beutler and J. Hoffman (2011) *Discovered sensors of innate immunity (Toll-like receptors, TLR)*

- R. Steinman (2011) *Discovered new type of cell, dendritic cell, that controls adaptive immunity*
The immune system

Infection of the human body by pathogenic microorganisms such as bacteria, viruses, parasites or fungi triggers the immune response. It occurs in a two-step process: innate immunity halts the infection, and adaptive immunity subsequently clears it.
1. Innate immunity
Components of microorganisms bind to Toll-like receptors located on many cells in the body. This activates innate immunity, which leads to inflammation and to the destruction of invading microorganisms.

2. Adaptive immunity
Dendritic cells activate T lymphocytes, which initiates adaptive immunity. A cascade of immune reactions follows, with formation of antibodies and killer cells.