HIV and AIDS

Lecture 23
Biology 3310/W4310
Virology
Spring 2018

Nature is not human-hearted
Lao Tzu
Tao Te Ching
This tragedy was facilitated (or even caused) by human interventions: colonization, urbanization, and probably well-intentioned public health campaigns


Epidemiologic Notes and Reports

Pneumocystis Pneumonia --- Los Angeles

In the period October 1980-May 1981, 5 young men, all active homosexuals, were treated for biopsy-confirmed Pneumocystis carinii pneumonia at 3 different hospitals in Los Angeles, California. Two of the patients died. All 5 patients had laboratory-confirmed previous or current cytomegalovirus (CMV) infection and candidal mucosal infection. Case reports of these patients follow.

Patient 1: A previously healthy 33-year-old man developed P. carinii pneumonia and oral mucosal candidiasis in March 1981 after a 2-month history of fever associated with elevated liver enzymes, leukopenia, and CMV viruria. The serum complement-fixation CMV titer in October 1980 was 256; in may 1981 it was 32. The patient's condition deteriorated despite courses of treatment with trimethoprim-sulfamethoxazole (TMP/SMX), pentamidine, and acyclovir. He died May 3, and postmortem examination showed residual P. carinii and CMV pneumonia, but no evidence of neoplasia.

Patient 2: A previously healthy 30-year-old man developed P. carinii pneumonia in April 1981 after a 5-month history of fever each day and of elevated liver-function tests, CMV viruria, and documented seroconversion to CMV, i.e., an acute-phase titer of 16 and a convalescent-phase titer of 28 in anticomplement immunofluorescence tests. Other features of his illness included leukopenia and mucosal candidiasis. His pneumonia responded to a course of intravenous TMP/SMX, but, as of the latest reports, he continues to have a fever each day.

Editorial Note: Pneumocystis pneumonia in the United States is almost exclusively limited to severely immunosuppressed patients (1). The occurrence of pneumocystosis in these 5 previously healthy individuals without a clinically apparent underlying immunodeficiency is unusual. The fact that these patients were all homosexuals suggests an association between some aspect of a homosexual lifestyle or disease acquired through sexual contact and Pneumocystis pneumonia in this population. All 5 patients described in this report had laboratory-confirmed CMV disease or virus shedding within 5 months of the diagnosis of Pneumocystis pneumonia. CMV infection has been shown to induce transient abnormalities of in vitro cellular-immune function in otherwise healthy human hosts (2,3). Although all 3 patients tested had abnormal cellular-immune function, no definitive conclusion regarding the role of CMV infection in these 5 cases can be reached because of the lack of published data on cellular-immune function in healthy homosexual men with and without CMV antibody. In 1 report, 7 (3.6%) of 194 patients with pneumocystosis also had CMV infection '40% (21%) of the same group had at least 1 other major concurrent infection (1). A high prevalence of CMV infections among homosexual males was recently reported; 179 (94%) had CMV viruria; rates for 101 controls of similar age who were reported to be exclusively heterosexual were 54% for seropositivity and zero (0) viruria (4). In another study of 64 males, 4 (6.3%) had positive tests for CMV in semen, but none had CMV recovered from urine. Two of the 4 reported recent homosexual contacts. These findings suggest not only that virus shedding may be more readily detected in seminal fluid than urine, but also that seminal fluid may be an important vehicle of CMV transmission (5).

All the above observations suggest the possibility of a cellular-immune dysfunction related to a common exposure that predisposes individuals to opportunistic infections such as pneumocystosis and candidiasis. Although the role of CMV infection in the pathogenesis of pneumocystosis remains unknown, the possibility of P. carinii infection must be carefully considered in a differential diagnosis for previously healthy homosexual males with dyspnea and pneumonia.
AIDS

- Clusters of PCP and Kaposi’s sarcoma observed in other urban centers
- CDC established case definition of KS or opportunistic infections
- 1982 disease was called AIDS (formerly GRID)
- Found transmitted at birth and heterosexually, blood products
HIV is a lentivirus

- First isolated in 1983 from the lymph node of a patient with lymphadenopathy in Paris; 2008 Nobel to Montagnier & Barré-Sinoussi
- 1984 blood test developed
- Electron microscopy and sequence analysis revealed HIV to be a lentivirus, known group of retroviruses
Retroviridae

- **Orthoretrovirinae (subfamily)**
  - *Alpharetrovirus* (*Avian leukemia virus, Rous sarcoma virus*)
  - *Betaretrovirus*
  - *Gammaretrovirus*
  - *Deltaretrovirus* (*Human T cell lymphotrophic virus 1, 2, 3*)
  - *Epsilonretrovirus* (*Walleye dermal sarcoma virus*)
  - *Spumavirus*
  - *Lentivirus* (*Human immunodeficiency virus 1, 2*)
Two evolutionarily distinct groups of human retroviruses

- The lymphotropic viruses: HTLV 1, 2, 3, 4
- The immunodeficiency viruses: HIV-1, HIV-2
  - Lentiviruses, not new or unique to humans
  - Equine infectious anemia virus, causes fatal immunodeficiency of horses, isolated early 1900s
HIV and AIDS: Acquired ImmunoDeficiency Syndrome

- Syndrome: the occurrence together of a characteristic group or pattern of symptoms
- HIV-1 is the etiological agent of epidemic AIDS
- AIDS denialists: the hypothesis that HIV causes AIDS has been tested by inadvertent infection of people with HIV-contaminated blood
HIV/AIDS pandemic in the US

- In the US, HIV has killed over 600,000, exceeding all US combat-related deaths in all wars fought in the 20th century
- >1.2 million in the US are living with HIV; 13% unaware
- 39,782 new infections in 2016; 70% men, 30% women
- Half of all new infections in US occur in people 25 or younger
36.7 million people now estimated to be living with HIV 
[30.8–42.9 million]

During 2016...

1.8 million people newly infected 
[1.6–2.1 million]

1.0 million HIV-related deaths 
[830 000–1.2 million]
### Global summary of the AIDS epidemic | 2016

#### Number of people living with HIV in 2016

<table>
<thead>
<tr>
<th>Category</th>
<th>Total</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Adults</td>
<td>34.5 million</td>
<td>28.8 million – 40.2 million</td>
</tr>
<tr>
<td>Women</td>
<td>17.8 million</td>
<td>15.4 million – 20.3 million</td>
</tr>
<tr>
<td>Men</td>
<td>16.7 million</td>
<td>14.0 million – 19.5 million</td>
</tr>
<tr>
<td>Children (&lt;15 years)</td>
<td>2.1 million</td>
<td>1.7 million – 2.6 million</td>
</tr>
</tbody>
</table>

#### People newly infected with HIV in 2016

<table>
<thead>
<tr>
<th>Category</th>
<th>Total</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Adults</td>
<td>1.7 million</td>
<td>1.4 million – 1.9 million</td>
</tr>
<tr>
<td>Children (&lt;15 years)</td>
<td>160 000</td>
<td>100 000 – 220 000</td>
</tr>
</tbody>
</table>

#### AIDS deaths in 2016

<table>
<thead>
<tr>
<th>Category</th>
<th>Total</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Adults</td>
<td>890 000</td>
<td>740 000 – 1.1 million</td>
</tr>
<tr>
<td>Children (&lt;15 years)</td>
<td>120 000</td>
<td>79 000 – 160 000</td>
</tr>
</tbody>
</table>

*Source: UNAIDS/WHO estimates.*
Global estimates by WHO region, 2016

36.7 million people living with HIV globally

Africa: 25.6 million
Americas: 3.3 million
South-East Asia: 3.5 million
Europe: 2.4 million
Eastern Mediterranean: 360,000
Western Pacific: 1.5 million

Sources: GARPR 2016; UNAIDS 2016 estimates.
Decline in HIV incidence and mortality over time

Source: UNAIDS/WHO estimates.
2016: About 5,000 new HIV infections a day, 200 per hour
Control of AIDS

Triple-drug therapy has slowed the pandemic in countries with money
Estimated numbers of people receiving antiretroviral therapy globally and by WHO Region and percentage coverage globally, 2000–2015

- African Region
- Region of the Americas
- South-East Asia Region
- European Region
- Western Pacific Region
- Eastern Mediterranean Region

Source: Global AIDS Response Progress Reporting (UNAIDS/UNICEF/WHO) and UNAIDS/WHO estimates.
But...

- There is as yet no cure
  - Can’t clear virus from an infected individual
- There is no vaccine
  - Can’t block primary infection
- Can’t stop taking antiviral drugs
  - Reservoirs: latently infected hematopoietic progenitor cells
- Drug resistant viruses appear
- Drugs are expensive
First studies in Africa, in Zaire and Rwanda, showed that AIDS was common in Kinshasa and Kigali, where nearly 90% of sex workers were infected.
Testing of archival samples suggested that HIV-1 was present in the 1960s and 1970s in several locations in central Africa but not in West or East Africa.

Serum sample ZR59 from a DRC adult male (1959) found positive for HIV-1 in 1998.

Lymph node sample from DRC adult female (1960).
Out of Africa

- DRC60 and ZR59 differed by about 12%
- No doubt that HIV-1 was present in Léopoldville (Kinshasa today) by 1959–60
What was the source of HIV-1?

- SIV first isolated from chimpanzee in 1989 (SIVcpz)
- Analysis of >7,000 chimpanzee fecal samples from 90 field sites confirmed natural SIVcpz reservoir
- Only *Pan troglodytes troglodytes* and *P. T. schweinfurthii* harbor SIVcpz
SIVcpz

- Transmitted among chimpanzees by sexual intercourse; mother to child; possibly blood-blood during aggression
- Estimated transmission probability per coital act 0.008 - 0.0015, similar to humans (0.0011)
- SIVcpz is pathogenic in natural host, similar to AIDS
HIV-1
M & N
HIV-1
P & O

P. t. t. of central Africa

Cold Spring Harb Perspect Med 2011;1:a006841
When did SIV infect humans?

- Four separate crossover events
- M, O: First three decades of 20th century
- N, P: more recently but not enough data

Cold Spring Harb Perspect Med 2011;1:a006841
How did SIVcpz infect humans?

- The cut hunter: bushmeat hunting
- Cutaneous or mucous membrane exposure to infected chimpanzee blood, body fluids
- Calculations suggest that in 1921 number of people infected with SIVcpz was <10, but probably only one spread and multiplied
- Such cross-species infections probably have occurred many times previously
- Why did this one spread?
• Leopoldville (Kinshasa) was the most dynamic city in the region, attracted large numbers of migrants and traders

• The cut hunter might have traveled there, visited a brothel, then a STD clinic

• Then amplification by non-sterile syringes, sex (some women had 1,000 clients/yr)

• Haiti and the Belgian Congo
Why did HIV-1 spread?

- European colonization of Africa beginning end of 19th century
- Establishment of large population centers, movement of adult males for labor - large scale prostitution
- Introduction of health care - colonial medicine - injections and transmission of viruses
- Egypt at turn of 20th century - well intentioned treatment for schistosomiasis spread HCV to millions
- Large scale amplification of HIV-1
Early HIV/AIDS in North America
HIV-2

- First isolated in Guinea-Bissau, 30-40% identity to HIV-1.
- Restricted primarily to populations in West Africa.
- Less virulent (most infections do not progress to AIDS), transmissible than HIV-1, no mother-infant spread.
- Crossover from sooty mangabey.
- 8 distinct lineages, each arose from separate infection.
HIV-1 diversity

- Four groups based on sequence alignment
- Group M (main): 99% of all HIV-1 infections
- Group O (outlier): <1% of infections, limited to Cameroon, Gabon, neighboring countries
- Group N: Only 13 cases, Cameroon
- Group P: Only 2 cases, Cameroon
- *Each from an independent transmission event of SIV to humans*
- HIV-1 group M further divided into 9 subtypes
- High-risk individuals multiply infected, recombinants emerge (CRFs) 48 so far
- No clear cut difference between subtypes in propensity to cause AIDS, except that those infected with D die faster
- Shedding of subtype C in female genital tract is higher, perhaps higher female to male transmission, extensive spread in Africa
HIV-1 subtypes

- HIV-1 evolves in one direction to numerous subtypes and recombinants
- Therefore can reconstruct sequence of progress in region or country by examining local distribution of subtypes
- Facilitated in 1990s by new tools enabling examination of nucleotide sequences from large number of isolates
- Extreme diversity of HIV-1 in central Africa, clearly the origin as had more time to diversify
HIV-1 subtypes

- Some subtypes associated in specific locations with modes of transmission
- Founder effect: subtype will *predominate* in at-risk group
- Example: subtype B found in 96% of white homosexuals in South Africa (imported from US); subtype C accounts for 81% of infections of black heterosexuals
• Subtype C (50%), B and A (10-12%), G (6%), CRF02_AG (5%), CRF01_AE (5%), D (2.5%) of all HIV-1 infections

• Subtypes F, H, J, K limited transmission (<1%)
Transmission

- HIV is not a particularly infectious virus, not contagious like measles virus ($R_0$ 2-5)
- Not spread by respiratory, alimentary, or vector routes
# Isolation of infectious HIV-1 from body fluids

<table>
<thead>
<tr>
<th>Fluid</th>
<th>Virus isolation</th>
<th>Estimated quantity of virus</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cell-free fluid</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cerebrospinal fluid</td>
<td>21/40</td>
<td>10–10,000</td>
</tr>
<tr>
<td>Ear secretions</td>
<td>1/8</td>
<td>5–10</td>
</tr>
<tr>
<td>Feces</td>
<td>0/2</td>
<td>None detected</td>
</tr>
<tr>
<td>Milk</td>
<td>1/5</td>
<td>&lt;1</td>
</tr>
<tr>
<td>Plasma</td>
<td>33/33</td>
<td>1–5,000(^d)</td>
</tr>
<tr>
<td>Saliva</td>
<td>3/55</td>
<td>&lt;1</td>
</tr>
<tr>
<td>Semen</td>
<td>5/15</td>
<td>10–50</td>
</tr>
<tr>
<td>Sweat</td>
<td>0/2</td>
<td>None detected</td>
</tr>
<tr>
<td>Tears</td>
<td>2/5</td>
<td>&lt;1</td>
</tr>
<tr>
<td>Urine</td>
<td>1/5</td>
<td>&lt;1</td>
</tr>
<tr>
<td>Vaginal-cervical</td>
<td>5/16</td>
<td>&lt;1</td>
</tr>
<tr>
<td><strong>Infected cells</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bronchial fluid</td>
<td>3/24</td>
<td>Not determined</td>
</tr>
<tr>
<td>PBMC</td>
<td>89/92</td>
<td>0.001–1(^d)</td>
</tr>
<tr>
<td>Saliva</td>
<td>4/11</td>
<td>&lt;0.01%</td>
</tr>
<tr>
<td>Semen</td>
<td>11/28</td>
<td>0.01–5%</td>
</tr>
<tr>
<td>Vaginal-cervical fluid</td>
<td>7/16</td>
<td>Not determined</td>
</tr>
</tbody>
</table>
Transmission

- HIV-1 infectivity reduced by air drying (99%/24 hr)
- By heating (56°C/30 min)
- By 10% bleach or 70% alcohol
- By pH extremes (<6 or >10)
- STD/IVDU bypass these!
## Risk of transmission of HIV-1

<table>
<thead>
<tr>
<th>Mode</th>
<th>Risk</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Sexual transmission</strong></td>
<td></td>
</tr>
<tr>
<td>Female-to-male</td>
<td>1 in 700 to 1 in 3,000</td>
</tr>
<tr>
<td>Male-to-female</td>
<td>1 in 200 to 1 in 2,000</td>
</tr>
<tr>
<td>Male-to-male</td>
<td>1 in 10 to 1 in 1,600</td>
</tr>
<tr>
<td><strong>Parenteral</strong></td>
<td></td>
</tr>
<tr>
<td>Transfusion of infected blood</td>
<td>95 in 100</td>
</tr>
<tr>
<td>Needle sharing</td>
<td>1 in 150</td>
</tr>
<tr>
<td>Needle stick</td>
<td>1 in 200</td>
</tr>
<tr>
<td>Needle stick /AZT PEP</td>
<td>1 in 10,000</td>
</tr>
<tr>
<td><strong>Mother to infant</strong></td>
<td></td>
</tr>
<tr>
<td>Without AZT</td>
<td>1 in 4</td>
</tr>
<tr>
<td>With AZT</td>
<td>&lt;1 in 10</td>
</tr>
</tbody>
</table>
Co-receptors

HIV (X4) interacts with the α-chemokine receptor (CXCr4) and CD4 to enter the target cell. Sdf-1 binds to CD4+ target cell.

HIV (R5) interacts with the β-chemokine receptor (CCR5) and CD4 to enter the target cell. Other β-chemokine receptors (CCl 3, CCl 4) are also involved.
Host genes that determine susceptibility

- Ccr5-delta32 mutation protects vs HIV-1 infection
- Present in 4-16% of European descent
- Stem cell therapy cured German AIDS patient [http://www.virology.ws/2014/09/06/the-berlin-patient/]
- Disrupting ccr5 with nucleases, crispr/cas9
Primary HIV Infection

- Virus-dendritic cell interaction (no activation)
  - Infection typically with CCR5 binding strains
  - Importance of DC-SIGN (dendritic cell-specific, Icam-3 grabbing nonintegrin)

- Delivery of virus to lymph nodes

- Active replication in lymphoid tissue

- High levels of viremia and dissemination

- Down-regulation of virus replication by immune response

- Viral set point reached after ~6 months
Primary HIV Infection: Clinical characteristics

- 50-90% of infections are symptomatic
- Symptoms generally occur 5-30 days after exposure
- Symptoms and signs
  - Fever, fatigue, malaise, arthralgias, headache, nausea, vomiting, diarrhea
  - Lymphadenopathy, pharyngitis, rash, weight loss, mucocutaneous ulcerations, aseptic meningitis
  - Leukopenia, thrombocytopenia, elevated liver enzymes
- Median duration of symptoms: 14 days
Established HIV Infection

- Active viral replication throughout course of disease
- Major reservoirs of infection exist outside of blood
  - Lymphoreticular tissues (bone marrow, lymph nodes, spleen, MALT)
  - Central nervous system
  - Genital tract
- At least $10 \times 10^9$ virions produced and destroyed each day
- $T_{1/2}$ of HIV in plasma is $<6$ h and may be as short as 30 min
GI associated lymphoid tissue following acute infection

Absence of lymphoid cell aggregates in terminal ileum
The variable course of HIV-1 infection

Typical Progressor

- Primary HIV Infection
- Clinical Latency
- AIDS

Rapid Progressor

- Primary HIV Infection
- AIDS

Nonprogressor

- Primary HIV Infection
- Clinical Latency

Viral Replication
- months
- years

CD4 Level

Virology Lectures 2018 • Prof. Vincent Racaniello • Columbia University
Elite HIV Controllers

- Individuals who maintain normal CD4 counts and undetectable viral loads (1-30 copies HIV RNA/ml of plasma) for >10 years in the absence of antiretroviral therapy
  - Estimated at 1/300 infected persons
- Associated with favorable HLA (MHC) types (esp HLA B57 and B27) and T-cell responses (CD4 and CD8) to Gag
- Not associated with attenuated viruses
## Immune cell dysfunction in AIDS

<table>
<thead>
<tr>
<th>Cell-type affected</th>
<th>Major dysfunction</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>CD4⁺ T cells</strong></td>
<td>Total number decreases</td>
</tr>
<tr>
<td></td>
<td>Expression of IL-2 decreases</td>
</tr>
<tr>
<td></td>
<td>Expression of IFNγ decreases</td>
</tr>
<tr>
<td><strong>CD8⁺ T cells</strong></td>
<td>Total number increases and then decreases</td>
</tr>
<tr>
<td></td>
<td>Loss of anti-HIV activity</td>
</tr>
<tr>
<td><strong>B cells</strong></td>
<td>Abnormal proliferation</td>
</tr>
<tr>
<td></td>
<td>Poor antigen response</td>
</tr>
<tr>
<td></td>
<td>Production of autoantibodies</td>
</tr>
<tr>
<td><strong>Monocytes</strong></td>
<td>Total number decreases</td>
</tr>
<tr>
<td></td>
<td>Antigen-presentation decreases</td>
</tr>
<tr>
<td></td>
<td>Fc receptor function decreases</td>
</tr>
<tr>
<td><strong>Dendritic cells</strong></td>
<td>Bystander killing by increased</td>
</tr>
<tr>
<td></td>
<td>cytokine production</td>
</tr>
<tr>
<td><strong>Macrophages</strong></td>
<td>Cytotoxicity function decreases</td>
</tr>
<tr>
<td><strong>NK cells</strong></td>
<td></td>
</tr>
</tbody>
</table>
AIDS

Acute phase
- Mononucleosis-like syndrome:
  - Lymphadenopathy
  - Diarrhea, etc.

Asymptomatic phase
- Often none, sporadically:
  - Fatigue,
  - Mild weight loss
  - Generalized lymphadenopathy
  - Thrush
  - Oral hairy leukoplakia
  - Shingles

Establishment of reservoirs

Symptomatic phase
- B. Fewer than 200 CD4⁺ T cells/ml:
  - Protozoal, bacterial, and fungal infections
  - Viral infections and malignancies
  - Neurological symptoms

A. 200–500 CD4⁺ T cells/ml:
- Oral lesions, shingles, skin lesions
- Low platelet count
- Basal cell carcinoma of the skin
- Headache
- Genital warts
- Reactivation of latent Mycobacterium tuberculosis

Continuous, low virus production. Virus evolution
Neurological symptoms

- Inflammatory: CNS toxicity
  - Chemokines (CCL2, CCL4)
  - Endothelin-1 (vasoconstriction)
  - Nitric oxide (neuronal cell death)

- CNS disease in children
  - Quinolinic acid
  - Arachidonic acid metabolites
  - Platelet-derived activation factor

- Cytokines: CNS toxicity
  - TGF-β
  - IL-6
  - TNF-α
  - IL-10
  - Toxic factors (heat stable, heat labile)
HIV and cancer

- HIV-1 infection leads to increase incidence of malignancy: 40% of infected individuals
- An indirect effect of dysregulation of the immune system
  - Absence of proper immune surveillance
  - High levels of cytokines leads to inappropriate cell proliferation, replication of oncogenic viruses (EBV, HHV8, HPV), angiogenesis
Kaposi’s sarcoma

- Described 1872 by Hungarian physician
- Pre-AIDS: mainly in older Mediterranean men
- Occurs in 20% of HIV-1 infected homosexual men, 2% of HIV-1 infected women, transfusion recipients
- Infection with human herpesvirus 8 is necessary for development of KS
Is an HIV-1 vaccine possible?

How does HIV-1 persist despite effective anti-viral immunity?
How does it eventually outstrip immune control?
HIV-1 superinfection occurs less frequently than initial infection
HIV-1 escape from neutralizing antibody
Prime-boost: ALVAC-HIV (gag, pol, env in canarypox vector) and AIDSVAX B/E (recombinant gp120 protein)

16,000 adult volunteers in Thailand

6 prime, 6 boost injections

Lowered rate of HIV-1 infection by 31.2% compared with placebo

n=51 vs n=74
Broadly neutralizing antibodies

- Have been identified in 20% of HIV-1 infected individuals
- Neutralize broadly across subtypes
- Recognize conserved epitopes on Env glycoprotein
Immunoprophylaxis vs AIDS

A.

VIP IgG expression vector — 4.5kb

ITR CASE IgG HC 2A LC WPRE SV40pA ITR

ssDNA

Humanized mouse

B.

HIV copies per ml plasma

Number of HIV challenges (weeks)

C.

% uninfected

Number of HIV challenges (weeks)

Luc VRC07W

P < 0.0001

n = 12–13
Global influenza 1996

HIV single individual 6 years after infection

HIV Amsterdam cohort 1991

Congo 1997

CRF01

10%

Virology Lectures 2018 • Prof. Vincent Racaniello • Columbia University
~1921: Patient zero

78,000,000 infections
35,000,000 deaths