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M1 - Immunology, Winter 2008

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Objectives

The objectives of this lecture are to understand:

1. The Pathogenesis of Autoimmune Diabetes (Type 1A diabetes)
2. The role of T cells in Disease Pathogenesis
3. The role of Cytokines in Disease Pathogenesis
4. The role of Islet Autoantibodies
Diabetes Mellitus

A systemic disease with multiple metabolic abnormalities, chief among which is an elevation in plasma glucose.

In addition to the primary defect in carbohydrate metabolism defects in lipid metabolism are widespread, with elevations in plasma FFA and TG, and, in some circumstances, of ketones.
The Expert Committee on the Diagnosis and Classification of Diabetes Mellitus

I. Type 1 diabetes  
   A. Immune mediated  
   B. Idiopathic

II. Type 2 diabetes

III. Other specific types
Regulation of Plasma Glucose

Steady State Plasma Glucose

Glucose Production

Liver

Glucose Disposal

Peripheral Tissues
Regulation of Plasma Glucose

Glucose Production = Steady State Plasma Glucose = Glucose Disposal

- Liver
- Peripheral Tissues
Diabetes Mellitus- Type 1

Increased thirst (polydypsia)
Increased urination (polyuria)
Increased appetite (polyphagia)
Weight loss
Fatigue
Rapid, early onset (before age 15)
## Differences Between Type 1 and Type 2 Diabetes

<table>
<thead>
<tr>
<th></th>
<th>Type 1</th>
<th>Type 2</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Age of onset</strong></td>
<td>Young</td>
<td>Older</td>
</tr>
<tr>
<td><strong>Type of onset</strong></td>
<td>Acute</td>
<td>Insidious</td>
</tr>
<tr>
<td><strong>Genetic background</strong></td>
<td>HLA related</td>
<td>Not HLA related</td>
</tr>
<tr>
<td><strong>Islet cell antibodies</strong></td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td><strong>Insulin secretion</strong></td>
<td>Absent</td>
<td>Present</td>
</tr>
<tr>
<td><strong>Nutritional status</strong></td>
<td>Thin</td>
<td>Obese</td>
</tr>
<tr>
<td><strong>Insulin dependence</strong></td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td><strong>Insulin resistance</strong></td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td><strong>Responsiveness to Orals</strong></td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td><strong>Ketosis proneness</strong></td>
<td>Yes</td>
<td>No</td>
</tr>
</tbody>
</table>
Relative Proportions of Types 1 & 2 DM

- Type 2: 95%
- Type 1: 5%
Type 1 diabetes (IDDM)

Chronic autoimmune disease with juvenile onset, but may develop in adults as well as elderly (LADA).

**Polygenic disease**
- Strong MHC linkage
- Non-MHC genes

**Autoimmune etiology**
- Antibodies to islet autoantigens
- Autoreactive T cells

**Immune-modulation alters the course of disease**
- Antigen vaccination
- General immunosuppression
Stages in Development of Type 1 Diabetes

- **Genetically at Risk**
- **Multiple Antibody Positive**
- **Loss of First Phase Insulin Response**
- **Newly Diagnosed Diabetes**

Type 1 diabetes: a chronic inflammatory disease of the islets

Genetic Susceptibility
Empiric risk of developing Type 1 diabetes

<table>
<thead>
<tr>
<th>Relative Category</th>
<th>Empiric Risk</th>
</tr>
</thead>
<tbody>
<tr>
<td>First degree relatives of T1DM probands*</td>
<td>5-7%</td>
</tr>
<tr>
<td>Individuals without relatives with T1DM*</td>
<td>&lt;1%</td>
</tr>
<tr>
<td>Children of affected father**</td>
<td>~6%</td>
</tr>
<tr>
<td>Children of affected mother**</td>
<td>~2%</td>
</tr>
</tbody>
</table>

These estimates are for North American Caucasian* and Scandinavian populations**
The Wellcome Trust Case Control Consortium (WTCCC) primary genome-wide association (GWA) scan in T1DM

HLA

Human Leukocyte Antigen

human MHC

cell-surface proteins

important in self vs. nonself distinction

present peptide antigens to T cells

CLASS I: A, B, C

CLASS II: DR, DQ, DP
The Human Leukocyte Antigen Complex (6p21.31)

- **Class II** (1.1 Mb): DP, DQ, DR
- **Class III** (0.7 Mb): B, C, A
- **Class I** (2.2 Mb)

- **Frequent Recombination**
- **Complement and Cytokines**
- **Recombination is Rare**
- **Recombination is Rare**
- **Class I-like genes and pseudogenes**

**Telomere**

**Centromere**
MHC Haplotype Sharing Increases DR3/4 Sibling Risk

Haplotype Determination:

**siblings share both haplotypes**
- Family A
  - Haplotypes: A1 B2 C29 D2
  - HLA-A: 1 29
  - HLA-DRB1: A3 B4 C3 D4

**siblings share one haplotype**
- Family B
  - Haplotypes: A2 B68 C1 D30
  - HLA-A: 2
  - HLA-DRB1: A4 B8 C3 D3

**siblings share no haplotype**
- Family C
  - Haplotypes: A2 B1 C31 D3
  - HLA-A: 1
  - HLA-DRB1: A3 B4 C4 D4

Diabetic Proband
- Family A: HLA-A: 1 29
  - HLA-DRB1: A3 B4

DAISY Sibling
- Family A: HLA-A: 1 29
  - HLA-DRB1: A3 B4
MHC haplotype sharing increases risk in DR3/4-DQ8 siblings

% Autoantibody Positive

% Diabetic

Age (y)

Source: Aly T et al. PNAS, 2006
Multiple Factors May Drive Progressive Decline of $\beta$-Cell Function

- Hyperglycemia (glucose toxicity)
- Apoptosis/Necrosis
- Islet Neogenesis
- Islet Autoantibodies
- Autoreactive T cells
- (Elevated cytokines IFN$\gamma$, IL-1$\beta$, TNF$\alpha$, etc.)
- Environmental Factors

$\beta$-cell

↑ Apoptosis/Necrosis
↓ Islet Neogenesis

Hyperglycemia (glucose toxicity)
Environmental Factors
Congenital Rubella Syndrome

- 30% diabetic usually early T1DM, some T2DM
- incubation period 5-20 yrs
- HLA-DR3 or 3/4 in those with diabetes
- other autoimmune diseases (thyroid, AD)
- molecular mimicry with a 52kD autoantigen
- animal model - Syrian hamsters
- No diabetes after postnatal infection or MMR vaccination
Other Environmental factors involved in Type 1 diabetes pathogenesis

- Cocksakie B Virus ? Molecular mimicry with he islet autoantigen glutamic acid decarboxylase (GAD)
- Enterovirus ?
- Streptozotocine (low doses) ?
Loss of self tolerance to self-antigens
Autoantigens in Diabetes

- Insulin
- Glutamic acid decarboxylase (GAD65)
- Islet autoantigen 512aa (ICA512/IA-2)
- Zinc Transporter Znt8
Is there a primary antigen or immune response to multiple antigens required for autoimmunity?

T cells specific for one antigen (insulin)

Insulitis

Epitope and antigen spreading, expansion

Diabetes

OR

T cells specific for multiple antigens

Insulitis

Expansion of T cells

Diabetes

Krishnamurthy et al  JCI:116:3258, 2006
Role of T cells
Pathogenic Cells in Type 1 diabetes

Cell-mediated Immunity

• CD4+ T cells-MHC class II molecules (APC) interaction
• CD8+ T cells-MHC class I molecules (APC) interaction
• NK cells ?
• Macrophages ?
• Dendritic cells ?
INSULITUS. PATIENT DIED FROM DKA
Type 1 diabetes pathogenesis: alteration between pathogenicity (T effector cells) and regulation (regulatory T cells)

T1D Development

Contributing Factors

Pathogenicity  Regulation

Normal

T1D Prone

Pathogenicity  Regulation

T1D Protected

Pathogenicity  Regulation
Example of regulatory T cell defect: X-linked autoimmunity-immunodeficiency syndrome (XLAAD)

Gene defect: FOXP3

• This genetic defect can lead to Type 1 diabetes in the presence of other autoimmune disorders for abnormalities in regulatory T cell maturation.
Regulatory T cells (Tregs)

Thymus

Periphery

Naïve CD4⁺

CD4⁺CD25⁺ FoxP3⁺

FoxP3

TGF-β1

IL-6

IL-12

IL-23

IL-17

IL-4

IFN-γ

Th1

Th2

Th17

Treg

TGF-β1 others
Role of cytokines
Differentiation of CD4+ T-cell Subsets

- **IL-12**: Induces Th1 cells
  - Production of IFN-γ
  - IL-2
  - Cell-Mediated Immunity
  - Autoimmunity
  - Pro-Inflammation
  - Allograft Rejection

- **IL-10**: Induces Tr1 cells
  - Production of IL-10
  - TGF-β
  - Suppressor/Regulatory function
  - Humoral Immunity
  - Anti-Inflammatory

- **IFN-α**: Induces Tn cells
  - Production of IL-4
  - IL-5
  - Humoral Immunity
  - Anti-Inflammatory

- **IL-4**: Induces Th2 cells
  - Production of IL-4
  - IL-5
  - Humoral Immunity
  - Anti-Inflammatory
Oxidative Stress

IL-β, IFN-γ, TNF-α → Nitric Oxide (NO) production → Oxidative Stress → β-cell death
Role of autoantibodies
Cytoplasmic Islet-cell-antibody staining

Positive reaction

Negative reaction

Source: Diabetes Care, 1988
Islet Cell Autoantibody Assays

GAD65 Autoantibodies

IA-2 Autoantibodies
Immunoprecipitation of *in vitro* transcribed/translated \[^{35}\text{S-Met}\] labeled antigen using patient serum. [CV: inter-assay: 9.5%; intra–assay: 12.4%]

Insulin Autoantibodies (IAA)
New Radioimmunoassay [CV: inter-assay: 19.4%; intra-assay: 8%]

Islet Cell Antibodies (ICA)
Immunoperoxidase staining in rat and human pancreas
Prospective Studies in First Degree Relatives of T1DM Probands

Sibling/offspring cohort
Cumulative risk of developing clinical Type 1 diabetes in relatives of T1DM patients using islet autoantibodies (IAA, GAD65, IA-2, ICA)

Log Rank
P < 0.00001
Objective: To determine whether any immunomodulatory therapy can ameliorate insulin secretion in newly diagnosed T1DM (17-40 yr of age) and to ultimately prevent T1DM onset in first-degree relatives of T1DM probands. First trials in relatives started in 2003.

Criteria for enrolling T1DM patients in TrialNet: ≥ 2Ab to islet antigens.

Type I Diabetes TrialNet

http://www2.diabetestrialnet.org/
Conclusions

• Type 1 diabetes mellitus is a polygenic disease. Although at least 19 T1DM-related candidate genes have been identified, polymorphic regions within the HLA complex confers the strongest diabetogenic effect.

• CD4+ and CD8+ T cell responses to islet autoantigens (insulin, GAD65 and IA-2) are pathogenic.

• A defect of Regulatory T cells in suppressing pathogenic autoimmune responses is associated with Type 1 diabetes.

• The proinflammatory cytokines IL-1β, IFN-γ and TNF-α can cause β cell death (increased NO production).

• Gene defects in FOXP3 and AIRE cause multiple autoimmune disease (APECED, APS-I respectively) including Type 1 diabetes.

• The presence of multiple autoantibodies to insulin, GAD65, IA-2 are high risk markers of Type 1 diabetes progression.