A 24-Year Enzyme Replacement Therapy in an Adenosine-deaminase-Deficient Patient

Hana M. Tartibi, MD, Michael S. Hershfield, MD, Sami L. Bahna, MD, DrPH

Allergy and Immunology Section, Louisiana State University Health Sciences Center, Shreveport, Louisiana; and Department of Biochemistry, Duke University Medical Center, Durham, North Carolina

Dr Tartibi provided clinical care of the patient, drafted the initial manuscript, and participated in preparing the final manuscript; Dr Hershfield provided expert special laboratory tests, offered guidance in patient management, and participated in preparing the final manuscript; Dr Bahna provided clinical care of the patient and participated in preparing the final manuscript; and all authors approved the final manuscript as submitted and agree to be accountable for all aspects of the work.

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Address correspondence to Sami L. Bahna, MD, Allergy & Immunology Section, Louisiana State University Health, 1501 Kings Highway, Shreveport, LA 71130-3932. E-mail: sbahna@lsuhsc.edu

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The adenosine deaminase (ADA) enzyme is found in all cells, particularly the lymphocytes, and is essential for T-cell function. It deaminates adenosine (AXP) and 2′-deoxyadenosine. Mutations in the gene coding for ADA cause deficiency of this enzyme, which leads to elevated levels of deoxyadenosine triphosphate, which is cytotoxic and leads to cell apoptosis. ADA-deficient patients have dysfunction in all lymphocyte subtypes that results in severe combined immunodeficiency (SCID), a lethal disease during early childhood. ADA-deficient SCID patients comprise ~15% of all SCID cases and has the best prognosis with early immune reconstitution with stem cell transplantation or stem cell–targeted gene therapy (GT).

We report here the clinical course of a child, for whom immune reconstitution was not available, that we have been managing for 24 years on ADA enzyme replacement therapy. To our knowledge, this time frame is possibly the longest reported duration of such treatment.

CASE REPORT

Chief Complaint

Our patient presented at 3.5 months of age with fever and cough for a few days, diarrhea for 3 weeks, and oral thrush for 3 months. On physical examination, he had a temperature of 38.3°C, a respiratory rate of 25 breaths/min, a heart rate of 150 beats/min, and a weight of 8 lb 8 oz (<3rd percentile). The patient was
moderately dehydrated and appeared generally ill. He had severe oral thrush but no visible tonsils, palpable lymph nodes, or organomegaly. Chest auscultation showed clear lungs and normal heart sounds.

**Birth History**

Our patient was born term by cesarean delivery with a birth weight of 7 lb 12 oz to a 32-year-old G1 mother who received ampicillin-sulbactam before delivery because of fever. The amniotic fluid was meconium stained. The patient had poor Apgar scores of 4 and 6, bradycardia, and apnea requiring temporary intubation. Four hours’ postdelivery, he became tachypneic, with partial pressure of oxygen of 65 mm Hg and a base deficit of 4.7 mEq/L. His chest radiograph showed bilateral mild patchy infiltrates. He improved on ampicillin and amikacin. At discharge from the hospital, the patient had a white blood cell count of 3100/μL with 82% polymorphonuclear cells, 1% bands, 3% monocytes, 14% eosinophils, and no lymphocytes.

**Family History**

The patient had no siblings, and there was no history of early deaths or immunodeficiency diseases in family members.

**Laboratory Findings**

At the initial presentation (3.5 months), the patient had severe hypogammaglobulinemia and lymphopenia (Table 1). Both his B- and T-cell numbers were very low, and his isolate maglutamin titers were undetectable. Mitogen lymphoproliferative tests could not be performed because of his severe lymphopenia. Both the infant and his mother were HIV negative. His red blood cell count–ADA activity was barely detectable, and dAXP (total 2’-deoxyadenosine nucleotides) was 20.6% of total adenine nucleotides (normal <1%), confirming ADA-deficient SCID. Molecular genetic analysis showed he is heterozygous for 2 missense mutations (A179D and R211H). Both mutations have been found in other patients, with R211H more frequent than A179D.

**Clinical Course**

The patient was started on prophylactic trimethoprim/sulfamethoxazole, intravenous immunoglobulin (IVIg), and polyethylene glycol–conjugated adenosine deaminase (PEG-ADA) therapy at 30 U/kg (of ideal body weight) intramuscularly twice a week. His oral thrush improved with oral ketoconazole and topical nystatin treatment. A bone marrow transplant was considered, but no HLA-matched donor was found. His CD4 count increased from 109 cells/μL to 418 cells/μL in 1 month. He developed a urinary tract infection caused by *Escherichia coli* and had a good response to cefuroxime. At 9 months of age, the patient’s T cells showed normal mitogen proliferation response, and prophylactic trimethoprim/sulfamethoxazole was discontinued; 1 month later, IVIg was discontinued. He showed a marked increase in B cells, and his hemoglobin levels and platelet counts continued to be within normal limits. During his first year of life, the patient’s ADA levels were in the acceptable range, and he did not develop anti-ADA antibodies.

At 16 months of age (6 months after the IVIg was discontinued), the patient’s immunoglobulin levels were within normal limits: immunoglobulin G, 475 mg/dL; immunoglobulin A, 19 mg/dL; and immunoglobulin M, 59 mg/dL. During his early childhood, he had a few upper respiratory tract infections. He had 2 accidental exposures to varicella; he was given varicella zoster immune globulin and did not develop any skin lesions. Just before the patient turned 3 years old, he was hospitalized for 10 days for right middle lobe pneumonia and right otitis media that responded well to intravenous ceftriaxone. At that time, his PEG-ADA dose was 375 U once a week. At 3 years of age, he contracted meningocoecephalitis of unknown etiology; his PEG-ADA dose was increased to 375 U twice a week. His major illnesses during the subsequent years were *Staphylococcus coagulase*-negative bacteremia at 4 years of age and membranous glomerulonephritis at 18 years of age.

The patient’s PEG-ADA dose was periodically adjusted for weight, and he maintained plasma ADA levels in the range of 25 to 101 μmol/h/mL during the first year; 27 to 211 μmol/h/mL at 1 to 5 years of age; 63 to 152 μmol/h/mL at 6 to 10 years of age; and 29 to 101 μmol/h/mL at 11 to 24 years of age (Fig 1A). After the initiation of

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**TABLE 1 Patient’s Initial Immunologic Findings at 3.5 Months of Age**

<table>
<thead>
<tr>
<th>Laboratory Test</th>
<th>Finding</th>
<th>Normal Level</th>
</tr>
</thead>
<tbody>
<tr>
<td>WBC, 10^3/μL</td>
<td>9.8</td>
<td>6–17.5</td>
</tr>
<tr>
<td>Lymphocytes, 10^3/μL</td>
<td>0</td>
<td>2.5–12</td>
</tr>
<tr>
<td>Neutrophils, 10^3/μL</td>
<td>7</td>
<td>1–8.5</td>
</tr>
<tr>
<td>Eosinophils, 10^3/μL</td>
<td>2</td>
<td>0–0.3</td>
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<tr>
<td>IgA, mg/dL</td>
<td>&lt;7</td>
<td>2.9–125</td>
</tr>
<tr>
<td>IgG, mg/dL</td>
<td>&lt;189</td>
<td>251–1069</td>
</tr>
<tr>
<td>IgM, mg/dL</td>
<td>&lt;6</td>
<td>20–149</td>
</tr>
<tr>
<td>IgE, IU/mL</td>
<td>&lt;8.2</td>
<td>&lt;30</td>
</tr>
<tr>
<td>B cells/μL (CD19)</td>
<td>13</td>
<td>50–540</td>
</tr>
<tr>
<td>T cells/μL (CD3)</td>
<td>139</td>
<td>750–2790</td>
</tr>
<tr>
<td>T-helper cells/μL (CD4)</td>
<td>13</td>
<td>310–1920</td>
</tr>
<tr>
<td>T-suppressor cells/μL (CD8)</td>
<td>49</td>
<td>200–1320</td>
</tr>
<tr>
<td>T-helper/T-suppressor ratio (CD4/CD8)</td>
<td>0.3</td>
<td>&gt;0.9</td>
</tr>
<tr>
<td>Natural killer cells/μL (CD16/56)</td>
<td>43</td>
<td>30–300</td>
</tr>
<tr>
<td>IL-2, U/mL (secretion from CD3)</td>
<td>4</td>
<td>3–30</td>
</tr>
</tbody>
</table>

Ig, immunoglobulin; IL, interleukin; WBC, white blood cell count.
of PEG-ADA, there was a marked increase in his plasma ADA activity and lymphocyte count and a drop in red blood cell count–dAXP to barely detectable levels. His immunoglobulin levels have also been within normal range (Fig 1B). He currently continues to do well clinically, with no major infections. Table 2 displays the patient’s most recent immunologic evaluation at 24 years of age. His B- and T-cell proliferative responses to mitogens were good despite his mild lymphopenia and somewhat suboptimal lymphocyte viability (62.2%).

DISCUSSION

ADA-SCID, as with other types of SCID, is fatal unless diagnosed early and treated appropriately. Although a cure requires hematopoietic stem cell transplantation (HSCT) or GT, exogenous enzyme replacement therapy has been successful in prolonging the life of ADA-deficient patients. With HSCT from an HLA-matched sibling or family member, the survival rate is >80% at 6 years. The survival rate is much lower with HSCT from matched unrelated donors (67%), mismatched related donors (43%), and mismatched unrelated donors (29%). Advances in GT using bone marrow CD34+ cells with a low-intensity nonmyeloablative conditioning regimen have markedly increased its efficacy, with a resulting high survival rate.

Because neither HSCT nor GT was available for our patient at the time of his diagnosis, his treatment was based on ADA replacement therapy. PEG-ADA was first approved by the US Food and Drug Administration in 1990, shortly before our patient was diagnosed. Restoration of immune function usually occurs within 2 to 4 months of therapy. PEG-ADA therapy results in elimination of elevated intracellular levels of deoxyadenosine triphosphate, permitting the recovery of effective (although not normal) immune function. Dosing starts at 60 U/kg/week until the patient exhibits clinical improvement and an adequate plasma ADA level; it may then be reduced to 15 to 30 U/kg/week. In the first 8 to 10 years, PEG-ADA replacement therapy has been associated with less morbidity and mortality compared with haploidentical stem cell transplantations. Our patient maintained a good clinical course and immunologic status, including B-cell and T-cell functions despite a mild lymphopenia. His immunoglobulin levels have been within normal limits, which has not been the case for most patients treated solely with PEG-ADA.

PEG-ADA therapy requires monitoring of ADA and dAXP levels in erythrocytes to ensure adequate ADA activity. Low ADA levels and high erythrocyte dAXP levels should alert to the possibility of poor compliance, low dosage, improper storage (e.g., PEG-ADA should not be frozen), or the development of neutralizing anti-ADA antibodies. A laboratory at Duke University Medical Center has performed this biochemical monitoring for most of the US patients being treated with PEG-ADA, and data accumulated between April 1986 and September 2008...
Approximately 50% of patients started on PEG-ADA therapy
remained on it; ~20% had died while on therapy (mostly during the first 6 months), and ~30% underwent HSCT or GT. Of the patients being followed up on PEG-ADA therapy, 20% had been on therapy for 15 to 22 years. In general, after 10 to 15 years of therapy, the immune function declines; however, our patient who has been on therapy for 24 years has exhibited relatively normal immune function, sufficient to prevent frequent or opportunistic infections.

The restoration of immune function on long-term PEG-ADA therapy varies. In 2 series including a total of 19 patients (aged 5–15 years) and receiving therapy for 5 to 12 years, immune restoration was only partial. Although there was an initial improvement in lymphocyte counts, later T-cell and B-cell cytopenia and dysfunction occurred, but the natural killer cell count showed inconsistent change. Nevertheless, those patients had good general health and did not experience opportunistic infections. Initiating antimicrobial prophylaxis with trimethoprim/sulfamethoxazole and supportive immunoglobulin therapy is critical at the time of diagnosis, and it can usually be discontinued when immune restoration reaches a satisfactory level. In our patient, these treatments were discontinued at 9 months when he attained adequate levels of serum immunoglobulins and was maintaining a satisfactory clinical condition.

We previously reported a case of a 10-year-old boy treated with PEG-ADA for ~10 years, with normalization of his ADA and dAXP levels and a relatively healthy clinical course until he died of an Epstein-Barr virus–positive malignant brain lymphoma. It seems that PEG-ADA therapy can provide adequate immune restoration, but the risk of developing lymphoproliferative disorders remains. ADA deficiency can cause pulmonary alveolar proteinosis and inflammatory liver disease, which may respond to PEG-ADA therapy. In addition to the high financial cost ($100 000–$300 000 per year, depending on the dose), the aforementioned comorbid conditions make it important to consider potentially curative treatment with HSCT or GT whenever possible.

**CONCLUSIONS**

We describe a patient with ADA-SCID undergoing enzyme replacement therapy for 24 years, which is among the longest reported. Therapy was associated with a reduction in infections, particularly during his childhood, and no major infections through adulthood and without the development of autoimmune or lymphoproliferative disorders. Our report demonstrates the long-term efficacy of PEG-ADA in providing an adequate immune restoration and relatively good clinical well-being when curative HSCT or GT is not available.

**ACKNOWLEDGMENTS**

The authors acknowledge the excellent care provided to this patient by many pediatric residents and allergy/immunology fellows over the years. We also acknowledge the patient’s high degree of compliance with treatment and his consenting to our writing and publishing this report.

**ABBREVIATIONS**

ADA: adenosine deaminase
AXP: adenosine
dAXP: total 2′-deoxyadenosine nucleotides
GT: gene therapy
HSCT: hematopoietic stem cell transplantation
IVIg: intravenous immunoglobulin
PEG-ADA: polyethylene glycol–conjugated adenosine deaminase
SCID: severe combined immunodeficiency

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<th>Normal Level</th>
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</thead>
<tbody>
<tr>
<td>WBC, 10^3/μL</td>
<td>5.73</td>
<td>3.6–11.2</td>
</tr>
<tr>
<td>Lymphocytes, 10^3/μL</td>
<td>0.77</td>
<td>1–3</td>
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<tr>
<td>IgG, mg/dL</td>
<td>1120</td>
<td>700–1600</td>
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<td>IgA, mg/dL</td>
<td>232</td>
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<td>IgM, mg/dL</td>
<td>48</td>
<td>40–230</td>
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<td>IgE, IU/mL</td>
<td>585</td>
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<td>B cells/μL (CD19)</td>
<td>77</td>
<td>71–567</td>
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<tr>
<td>T cells/μL (CD3)</td>
<td>607</td>
<td>582–1992</td>
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<tr>
<td>T helper cells/μL (CD4)</td>
<td>207</td>
<td>401–1532</td>
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<tr>
<td>T suppressor cells/μL (CD8)</td>
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<td>152–838</td>
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<td>T helper/T suppressor ratio (CD4/CD8)</td>
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<td>NK cells/μL (CD16/56)</td>
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<td>80–597</td>
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<td>Diphtheria antibody, IU/mL</td>
<td>&lt;0.10</td>
<td>&gt;0.1</td>
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<tr>
<td>Tetanus antibody, IU/mL</td>
<td>1.05</td>
<td>&gt;0.15</td>
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<tr>
<td>Lymphocyte proliferation</td>
<td></td>
<td></td>
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<tr>
<td>Viable lymphocytes, %</td>
<td>62.2%</td>
<td>≥75%</td>
</tr>
<tr>
<td>Proliferation to PWM as % CD4</td>
<td>11.8%</td>
<td>≥4.5%</td>
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<tr>
<td>Proliferation to PWM as % CD3</td>
<td>12.8%</td>
<td>≥5.5%</td>
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<tr>
<td>Proliferation to PWM as % CD19</td>
<td>16.6%</td>
<td>≥5.9%</td>
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<tr>
<td>Proliferation to PHA as % CD4</td>
<td>61.7%</td>
<td>≥50%</td>
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<tr>
<td>Proliferation to PHA as % CD3</td>
<td>65.5%</td>
<td>≥50%</td>
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</table>

Ig, immunoglobulin; IL, interleukin; PHA, phytohemagglutinin; PWM, pokeweed mitogen; WBC, white blood cell count. *Expressed as percent increase from baseline to maximum stimulation.
REFERENCES


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