Severe, persistent, and fatal T-cell immunodeficiency following therapy for infantile leukemia

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We describe five cases of children who completed chemotherapy for infantile acute lymphoblastic leukemia (ALL) and soon after were diagnosed with severe T-cell, non-HIV immunodeficiency, with varying B-cell and NK-cell depletion. There was near absence of CD3⁺, CD4⁺, and CD8⁺ cells. All patients developed multiple, primarily opportunistic infections. Unfortunately, four patients died, although one was successfully treated by hematopoietic stem cell transplantation. These immunodeficiencies appeared to be secondary to intensive infant ALL chemotherapy. Our report highlights the importance of the early consideration of this life-threatening immune complication in patients who received chemotherapy for infantile ALL.

KEYWORDS
ALL, death, immunocompromised host, immunodeficiency, infant leukemia, molecular diagnosis and therapy

1 | INTRODUCTION

Intensification of therapy for infants with acute lymphoblastic leukemia (ALL) has resulted in fewer relapses, but at the cost of increased morbidity and death, especially during induction therapy. Increased nonhematological toxicity during modern treatment strategies for infant ALL has been reported, but severe immunodeficiency persisting after therapy has not been described.

Immunodeficiencies are classified as acquired or primary (PID). Congenital T-cell immunodeficiencies, defined as CD3⁺ less than 300 cells/μl, are generally more severe, compared to other immunodeficiencies, since T-cells also play a crucial role in the function of B-cells, NK-cells, and macrophages. Chemotherapy is known to induce an immunodeficiency state by significantly depleting T-cells, as well as NK-cells and B-cells. Usually, immune reconstitution begins after completing chemotherapy. In children, greater than 2 years of age, who received intense chemotherapy for treatment of high-risk ALL, T-cell recovery was complete 12–18 months after cessation of chemotherapy. In addition, the absolute CD3⁺ count at 1 month was greater than 300 cells/μl in these patients.

We describe five children who completed treatment for infantile ALL and soon after were diagnosed with persistent severe T-cell, non-HIV, immunodeficiency, with varying B-cell and NK-cell depletion, resulting in severe infections causing death in four and successful hematopoietic stem cell transplantation (HSCT) in one. The immune deficiency appeared to be secondary to their therapy. Our report highlights the importance of considering this complication in patients with infant ALL post chemotherapy.

2 | RESULTS

The IWK Health Centre Research Ethics Board reviewed this manuscript and provided a letter of support. We collected data on five infant cases, four females and one male, treated at three centers in North America between 1996 and 2015. Clinical and treatment characteristics are shown in Table 1. None of the patients received experimental agents or HSCT during initial treatment. All patients completed protocol therapy. Most patients developed infections during treatment despite intravenous immunoglobulins and pneumocystis prophylaxis as per protocol guidelines.

All patients were healthy with no hospital admissions prior to the diagnosis of ALL, except Patient E had a history of urinary tract infections, acute otitis media, and chronic rhinorrhea. These infections did not require hospital admission or intravenous antibiotics. None of the patients had a family history that placed them at risk for PID, except patient B. Her parents were third cousins and from a First Nation’s community in which children had previously been diagnosed with severe combined immunodeficiency (SCID), RAG2 mutation, for which
### TABLE 1  Patient information pertaining to leukemia diagnosis and treatment

<table>
<thead>
<tr>
<th>Patient</th>
<th>Diagnosis</th>
<th>Age at diagnosis</th>
<th>Treatment</th>
<th>Treatment complications</th>
<th>Age at end of chemotherapy treatment</th>
<th>Course after chemotherapy treatment</th>
<th>Age immunodeficiency confirmed</th>
<th>Therapy after ALL treatment</th>
<th>Current age or age at death</th>
<th>Autopsy results</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>MLL-R ALL</td>
<td>5 month old</td>
<td>COG AALL0631(^a)</td>
<td>Bacterial and fungal infections</td>
<td>29 month old</td>
<td>CMV viremia and cystitis, <em>Clostridium difficile</em> colitis, <em>Mycobacterium chelonae</em> cellulitis</td>
<td>31 month old</td>
<td>None</td>
<td>31 month old (deceased)</td>
<td>Disseminated aspergillosis; severe thymic involution; lymphoid depletion</td>
</tr>
<tr>
<td>B</td>
<td>MLL-R ALL</td>
<td>5 month old</td>
<td>COG AALL0631(^b)</td>
<td>Bacterial and viral infections, extensive thrombi involving upper venous system, enteritis</td>
<td>29 month old</td>
<td><em>Clostridium difficile</em> colitis, oral herpes simplex virus, norovirus, bocavirus, rhinovirus, and HHV-6 viremia, <em>Enterobacter cloacae</em> cysitis, pneumatosis intestinalis</td>
<td>31 month old</td>
<td>Interleukin-7</td>
<td>35 month old (deceased)</td>
<td>Diffuse bronchopneumonia; severe thymic involution, lymphoid depletion</td>
</tr>
<tr>
<td>C</td>
<td>MLL-R ALL</td>
<td>7 month old</td>
<td>COG AALL0631(^b)</td>
<td>None</td>
<td>31 month old</td>
<td><em>Mycobacterium chelonae</em> abscesses, parainfluenza-3, coronavirus, CMV retinitis, Candida esophagitis</td>
<td>44 month old</td>
<td>HSCT</td>
<td>50 month old (deceased)</td>
<td>Diffuse alveolar damage</td>
</tr>
<tr>
<td>D</td>
<td>MLL nonrearranged ALL</td>
<td>8 month old</td>
<td>CCG 1953</td>
<td>Bacterial and viral infections</td>
<td>33 month old</td>
<td><em>Pulmonary aspergillus, Pseudomonas sepsis</em></td>
<td>36 month old</td>
<td>None</td>
<td>37 month old (deceased)</td>
<td>Autopsy not performed</td>
</tr>
<tr>
<td>E</td>
<td>MLL nonrearranged ALL</td>
<td>11 month old</td>
<td>CCG P9407</td>
<td>Bacterial infections, chronic rhinorrhea/sinusitis</td>
<td>24 month old</td>
<td><em>Parainfluenza type 3</em> sinistitis, HHV-6 viremia, and encephalitis</td>
<td>31 month old</td>
<td>HSCT</td>
<td>8-year-old (alive)</td>
<td>Not applicable</td>
</tr>
</tbody>
</table>

**Notes:**
- ALL, acute Lymphoblastic leukemia; MLL, mixed lineage leukemia gene; MLL-R, MLL rearranged; COG, Children’s Oncology Group; CCG, Children’s Cancer Study Group; HSCT, hematopoietic stem cell transplant. CMV, cytomegalovirus; HHV-6, human herpesvirus 6.
- \(^a\)Treated before induction amendments.
- \(^b\)Treated after induction amendments (elimination of cyclophosphamide 1 g/m\(^2\)).

She tested negative. Patients A and C had normal newborn screening for SCID, using T-cell receptor excision circle (TREC) assays. All patients were HIV-negative before and after treatment.

After chemotherapy, patients were mildly to severely lymphopenic and developed recurrent or persistent infections. All were identified through formal immunology consultation to have a non-HIV acquired immunodeficiency between 2 and 13 months, median 3 months, after completing chemotherapy (Table 2). Three patients received additional therapy (one with interleukin-7 [IL-7] and two with HSCT) once the immunodeficiency was recognized. Unfortunately, four of the patients died with severe infections. Patient E was successfully treated with an unconditioned 10/10 HLA-matched unrelated donor HSCT.

### 3 | DISCUSSION

We describe the first report of non-HIV, persistent T-cell immunodeficiency, with varying B-cell and NK-cell depletion, in patients with infant ALL following modern intensive chemotherapy. Patients in our cohort remained mildly to severely lymphopenic and flow cytometry demonstrated extremely low CD3\(^+\), CD4\(^+\), and CD8\(^+\) T-cell populations consistent with a severe T-cell immunodeficiency despite completion of their chemotherapy treatment 2–13 months prior. We believe it is very unlikely that our patients had unrecognized PID. None of these patients had strong identifiers of PID, such as failure to thrive or intravenous antimicrobial use prior to ALL diagnosis. Patient B did have a distant family history of RAG2 deficiency but she did not carry this mutation. Investigations prior to starting chemotherapy suggested patients A, B, and C had been exposed to viral infections with no major complications. Finally, Patient E had an extensive genetic workup excluding common SCID mutations and Patients A and C had normal TREC assays. Based on the described history and investigations, we concluded these were secondary immunodeficiencies produced by the chemotherapy.

Studies of immune reconstitution in children who received chemotherapy for hematologic malignancy demonstrate that in most children total lymphocyte count recovered within 3–6 months. The total B-cell count is normal in most children by 1 month and all children by 6 months after chemotherapy cessation. NK-cells were...
initially thought to totally recover within 1 month of cessation, but more recent studies have shown a delayed drop that may take 6–12 months to fully recover.6,12,13

As for the T-cells, recovery of the CD4+ subset has been shown to have a direct relationship to the intensity of therapy and an inverse relationship with age.14 This inverse relationship is thought to have a direct relationship to the intensity of therapy and an inverse relationship with age.14

Thymic enlargement post chemotherapy has been demonstrated in pediatric patients.5 In most children treated for standard-risk and high-risk ALL, CD4+, and CD8+ T-cells require 3–18 months to recover and the CD3+ count at 1 month was greater than 300 cells/μl regardless of treatment intensity.5,6 Despite these prolonged impairments in immune function, severe opportunistic infections are not typically appreciated after cessation of chemotherapy, and death from infection is rare.13

In addition, cyclophosphamide and cytarabine have been associated with depletion of early lineage T-cells, thus affecting T-cell proliferation.15 Although Patient A was treated prior to cyclophosphamide being eliminated from AALL0631 induction, all of our patients were exposed to cumulative cyclophosphamide doses at least double that of standard-risk or high-risk ALL protocols used in older children.5 It is possible that these higher doses of cyclophosphamide (and cytarabine exposure) contributed to poor T-cell recovery. None of the studies examining immune reconstitution after chemotherapy have focused on infants; thus the pattern of immune recovery compared to older children is unknown.

All of our patients had severe T-cell deficiency with a CD3+ count less than 100 cells/μl, despite some being only mildly lymphopenic. The patients who underwent autopsy were found to have profound thymic involution, suggesting damage to the thymus, which likely contributed to poor T-cell recovery. Patient B was treated with IL-7 because of previous reports in patients post-HSCT or with HIV that CD4+ T-cells recovered with IL-7 therapy.16–19 Unfortunately, despite this treatment, her T-cells showed no signs of recovery.

These are the first reported cases of non-HIV, severe, persistent T-cell immunodeficiency, with varying B-cell and NK-cell depletion, secondary to infant ALL chemotherapy. These children may benefit from preemptive and aggressive infection management and/or require therapies to assist with immune reconstitution, such as HSCT. However, the prevalence of this complication is unknown. Formal evaluation to identify abnormal T-cell recovery should be considered in all patients with infant ALL following modern intensive chemotherapy protocols.

ACKNOWLEDGMENTS

We thank the patients and families described in this series.

*All, acute lymphoblastic leukemia; ALC, absolute lymphocyte count; IgG, immunoglobulin G; CMV, cytomegalovirus; EBV, Epstein-Barr Virus; PCR, polymerase change reaction; IgM, immunoglobulin M; TREC, T-cell receptor excision circles; RAG2, IL7RA, JAK3, DCLRE1C, and ADA are common mutations that cause severe combined immunodeficiency; PNP, purine nucleoside phosphorylase deficiency; n/a, information not available.

aPercentage of absolute lymphocyte count.

#TABLE 2 Immunologic investigations assessing immune function and causes of immune deficiency#

<table>
<thead>
<tr>
<th></th>
<th>Patient A</th>
<th>Patient B</th>
<th>Patient C</th>
<th>Patient D</th>
<th>Patient E</th>
<th>Normal range7–9</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Investigations at ALL diagnosis</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ALC (cells/μl)</td>
<td>14,600</td>
<td>12,700</td>
<td>0</td>
<td>n/a</td>
<td>n/a</td>
<td>3,400–9,000</td>
</tr>
<tr>
<td>IgG (g/l)</td>
<td>5.61</td>
<td>2.15</td>
<td>8.27</td>
<td>n/a</td>
<td>n/a</td>
<td>2.4–8.8</td>
</tr>
<tr>
<td>Abnormal viral serology</td>
<td>CMV IgM positive, CMV IgG positive</td>
<td>EBV IgG positive</td>
<td>CMV PCR positive</td>
<td>n/a</td>
<td>None</td>
<td></td>
</tr>
<tr>
<td><strong>Investigations after completion of chemotherapy treatment</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Time since completion of chemotherapy treatment</td>
<td>2 months</td>
<td>2 months</td>
<td>13 months</td>
<td>3 months</td>
<td>7 months</td>
<td></td>
</tr>
<tr>
<td>ANC (cells/μl)</td>
<td>2,389</td>
<td>2,400</td>
<td>882</td>
<td>21,597</td>
<td>4,290</td>
<td>2,000–7,100</td>
</tr>
<tr>
<td>ALC (cells/μl)</td>
<td>210</td>
<td>1,400</td>
<td>82</td>
<td>n/a</td>
<td>1,670</td>
<td>2,300–5,400</td>
</tr>
<tr>
<td>CD3+ (cells/μl)</td>
<td>82 (39% a)</td>
<td>14 (1%)</td>
<td>25 (38%)</td>
<td>n/a (1.7%)</td>
<td>&lt;17 (&lt;1%)</td>
<td>1,400–3,700 (56–75%)</td>
</tr>
<tr>
<td>CD4+ (cells/μl)</td>
<td>4 (2%)</td>
<td>14 (1%)</td>
<td>&lt;20 (&lt;1%)</td>
<td>n/a (0.5%)</td>
<td>&lt;17 (&lt;1%)</td>
<td>700–2,200 (28–47%)</td>
</tr>
<tr>
<td>CD8+ (cells/μl)</td>
<td>67 (32%)</td>
<td>0 (0%)</td>
<td>23 (35%)</td>
<td>n/a (0.7%)</td>
<td>&lt;17 (&lt;1%)</td>
<td>490–1,300 (16–30%)</td>
</tr>
<tr>
<td>CD19+ (cells/μl)</td>
<td>23 (11%)</td>
<td>1,065 (74%)</td>
<td>&lt;20 (&lt;1%)</td>
<td>n/a (1.6%)</td>
<td>1,486 (89.9%)</td>
<td>390–1,400 (14–33%)</td>
</tr>
<tr>
<td>CD56+ (cells/μl)</td>
<td>84 (40%)</td>
<td>187 (13%)</td>
<td>41 (62%)</td>
<td>n/a (93.7%)</td>
<td>167 (10.1%)</td>
<td>130–720 (4–17%)</td>
</tr>
<tr>
<td>IgG (g/l)</td>
<td>4.91</td>
<td>2.07</td>
<td>2.89</td>
<td>2.13</td>
<td>&lt;0.33</td>
<td>7.1–11.6</td>
</tr>
<tr>
<td>Other</td>
<td>TREC normal</td>
<td>RAG2 gene normal</td>
<td>TREC normal</td>
<td>None</td>
<td>IL7RA, JAK3, DCLRE1C, ADA genes and PNP activity, all normal</td>
<td></td>
</tr>
</tbody>
</table>
CONFLICT OF INTEREST
The authors declare that there is no conflict of interest.

ABBREVIATIONS
ALL acute lymphoblastic leukemia
HSCT hematopoietic stem cell transplantation
PID primary immunodeficiency
SCID severe combined immunodeficiency
TREC T-cell receptor excision circle

REFERENCES