Contribution of alternative complement pathway to delayed hemolytic transfusion reaction in sickle cell disease.

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Table 1. Evaluation of complement pathway during DHTR episodes.

<table>
<thead>
<tr>
<th></th>
<th>DHTTR #2 (Day 6)</th>
<th>DHTTR #3 (Day 13) Pre 1st dose</th>
<th>DHTTR #3 (Day 38) Pre 2nd dose</th>
<th>(Day 127) Clinic visit</th>
</tr>
</thead>
<tbody>
<tr>
<td>C3a (25-88.2 ng/ml)</td>
<td>43.6</td>
<td>75.6</td>
<td>79.4</td>
<td>27.9</td>
</tr>
<tr>
<td>C3a (2.74-16.33 ng/ml)</td>
<td>26.8</td>
<td>25.1</td>
<td>23.2</td>
<td>17.3</td>
</tr>
<tr>
<td>Bb (0.49-1.42 mcg/mL) *</td>
<td>0.95</td>
<td>6.06*</td>
<td>1.53</td>
<td>0.96</td>
</tr>
<tr>
<td>SC5b-9 (≥ 244 ng/mL)</td>
<td>319</td>
<td>270</td>
<td>219</td>
<td>81</td>
</tr>
<tr>
<td>CH50 (101-310 units)</td>
<td>ND</td>
<td>335</td>
<td>320</td>
<td>352</td>
</tr>
<tr>
<td>C3 (71-150 mg/dL)</td>
<td>ND</td>
<td>135</td>
<td>ND</td>
<td>ND</td>
</tr>
<tr>
<td>C4 (15.7-47 mcg/mL)</td>
<td>ND</td>
<td>21.4</td>
<td>ND</td>
<td>ND</td>
</tr>
</tbody>
</table>

C3a: complement component fragment 3a; C3a: complement component fragment 5a; Bb: complement component fragment Bb; SC5b-9: soluble membrane attack complex; CH50: screening test for total complement activity; C3: complement component 3; C4: complement component 4; ND: not done. All testing was obtained in a CLIA certified hospital-based clinical laboratory. All normal values are in parenthesis under each value except for day 13 * (1.32-4.18 mcg/mL) due to variability seen with different ELISA kits. DHTR#2 signifies the second DHTR episode at 13.5 years of age with complement evaluation on day 6 of presentation. The complement testing under DHTR#3 reflects the ACP pathway testing on the days just prior to administration of eculizumab on days 14 and 39. Testing at Day 127 reflects baseline complement levels during a routine sickle cell clinic appointment when the patient was well. Fragment Bb is a serine protease that in combination with hydrolyzed complement factor 3 (C3H2O) generates the formation of C5bBb (C5 convertase), which amplifies the cleavage of C3 to produce C5a and C5b which results in local inflammation and RBC opsonization, respectively. Anaphylatoxins, C3a and C5a are involved in local inflammation and tissue damage. Terminal complex, C5b-9 contributes to intravascular hemolysis.
vation could have been caused either by DHTR, mycoplasma infection, or from a combination of the two in this case. Given her rapid improvement, eculizumab was not used during this episode.

Eight months later, the patient again presented with significant VOC pain and a HGB of 5.6 g/dL (Figure 1C), which dropped to 3.9 g/dL within 24 hours of admission (Figure 1C) in the absence of preceding RBC transfusion. Immunohematology testing reconfirmed the previous anti-Sda, but did not detect the previous anti-Dia, anti-S, or cold agglutinin. The DAT was negative. The patient received three units of extended phenotype-matched, crossmatch-compatible RBC units and was discharged home with an HGB of 9.5 g/dL. The patient presented again eight days later with generalized pain, fever, hemoglobinuria, and total hyperbilirubinemia of 7.3 mg/dL. Although her HGB was 11.0 g/dL on admission, it declined sharply (Figure 1C) with worsening symptoms of pain, altered mental status, and development of new diffuse pulmonary edema requiring positive airway pressure support. The blood smear was notable for occasional schistocytes. This episode of antibody-negative DHTR hyperhemolysis and multi-organ dysfunction prompted the administration of eculizumab 600mg intravenously along with transfusion of one unit (4 ml/kg) extended phenotype-matched and crossmatch-compatible RBCs. Within 48 hours, the patient’s mental status improved remarkably, she reported less pain, hemolysis declined, and the patient was weaned off respiratory support. Concurrent complement analyses revealed increased levels of Bb, C5a, and C5b-9 (DHTR#3 day 13, Table 1), reflecting complement activation. On day 20, the patient was discharged and closely followed up in the clinic. On day 39, a second dose of eculizumab 600mg was administered for downward drift in HGB (nadir: 5.4 g/dL). Following this, the patient’s HGB remained within her baseline range of 8-9 g/dL with no recurrence of laboratory evidence of hyperhemolysis. Steroids and erythropoietin were slowly weaned. The patient had received pneumococcal and meningococcal vaccinations as part of routine SCD standard-of-care and continued on a prophylactic antibiotic regimen during her treatment.

Currently, there is no consensus in the management of DHTR with ongoing hyperhemolysis in patients with SCD, when routine treatment measures are inadequate. This case highlights the potential contribution of ACP activation in DHTR hyperhemolysis. While new allo- and (cold) autoantibodies were identified during the second episode, these were not the cause of this patient’s illness. The combination of treatments used, including new immunosuppressive medications and eculizumab, likely contributed to the patient’s improvement.
DHTR episode, no new allo- or autoantibodies were detected during the third episode. Hyperhemolysis, organ dysfunction, and activation of ACP was present during the 3rd DHTR episode. The hemolysis associated with VOC, ACS or DHTR, results in elevated plasma heme, potentially saturating scavenging and detoxifying mechanisms of hemopexin and heme-oxygenase-1, respectively.6,7 Elevations in free heme would then be predicted to lead to additional endothelial damage, vaso-occlusion and activation of the alternative complement pathway, while inhibiting the classical pathway.8-11 A case of antibody-negative DHTR in which eculizumab was used to dampen the complement activation was recently reported.12 This and other reports have suggested the involvement of complement pathway in SCD and DHTR13,14; the present case is novel in that we employed sensitive markers to assess and confirm the activation of the ACP cascade during recurrent episodes of DHTR and at steady-state (Online Supplementary Figure S1). While these markers of the ACP do not necessarily shed light on the mechanism of ACP activation during DHTR, markedly elevated C5a, C5b-9 and most importantly Bb levels returned to normal levels as the patient recovered; plasma Bb levels provide a quantitative value of ACP activation. Plasma C3a levels were over 2.5 times above baseline but not over the normal range. Persistently elevated levels of CH50 even at day 127 could suggest continued low level baseline complement activation possibly due to ongoing chronic hemolysis. While the implementation of additional immunosuppressive therapies could have impacted this patient's outcome, the rapid response to eculizumab suggests that the reversal of hyperhemolysis may be due to the ability of eculizumab to block the downstream consequences of ACP. These laboratory and clinical findings strongly suggest that in this case, ACP was likely involved in DHTR with hyperhemolysis, and that ACP activation resolved after administration of eculizumab. However, as these are certainly correlative findings, definitive future studies are needed. As not all cases of DHTR may be accompanied by ACP activation or may benefit from eculizumab, analysis of ACP during DHTR episodes, especially when it is associated with hyperhemolysis and/or organ injury, may prove useful when assessing the potential benefit of eculizumab intervention. While additional studies are needed, including clinical assays that possess the ability to more completely assess complement function, early and appropriate administration of targeted therapy such as eculizumab may hold promise in the mitigation of potentially fatal complications in some patients. Future studies are needed to explore the mechanisms and potential role of prophylactic complement inhibition in patients with recurrent antibody-positive and antibody-negative DHTRs and those with minimal availability of antigen-compatible blood products.

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16. Stowell SR, Winkler AM, Maier CL, et al. Initiation and regulation of complement activation during recurrent episodes of DHTR and at steady-state (Online Supplementary Figure S1).