Analyses of Thrombocytopenia in Idiopathic Thrombocytopenic Purpura-Prone Mice by Platelet Transfer Experiments Between (NZW × BXSB)F<sub>1</sub> and Normal Mice

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Male (NZW × BXSB) F<sub>1</sub> (W/B F<sub>1</sub>) mice, which develop lupus nephritis, myocardial infarction, and thrombocytopenia, showed reduced platelet lifespan (PLS) and increased platelet-associated antibody (PAA) values. There were statistically significant correlations between the increase in PAA values and either the reduction in PLS or the decrease in platelet counts. This and the results of platelet transfer experiments between old male W/B F<sub>1</sub> mice and either female W/B F<sub>1</sub> or normal BALB/c mice indicate that PAA on the platelet surface play a crucial role in the destruction of platelets in W/B F<sub>1</sub> mice. The mechanism of thrombocytopenia observed here appears similar to that of human idiopathic thrombocytopenic purpura (ITP). Therefore, we think that W/B F<sub>1</sub> mice are a potentially useful animal model for investigating the effectiveness and mode of action of therapeutic agents in human ITP, and that they may provide additional information on the basic mechanisms of this autoimmune phenomenon.

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MATERIALS AND METHODS

Mice. BALB/c, BXSB, and NZW mice were originally purchased from Jackson Laboratories (Bar Harbor, ME). W/B F<sub>1</sub> (hybrid of NZW female and BXSB male) were raised under specific pathogen-free conditions in the animal facility of the Nippon Shinyaku Research Laboratories (Kyoto, Japan).

Platelet labeling and platelet kinetics studies. <sup>111</sup>In-tropolone was used for the labeling of platelets by the method of Dewanjee et al. It was made by mixing 100 µL of <sup>111</sup>In-0.04 mol/L HCl (Japan Mediphysics Co, Hyogo, Japan, 1 mCi/mL) and the same volume of tropolone solution (Sigma Co, St Louis, MO) with acid-citrate-dextrose (ACD-A, pH 4.5, 0.01 mol/L-saline at a concentration of 2 mg/mL), then incubated for 5 minutes at room temperature. Blood (1.5 mL) was obtained from the retro-orbital plexus of ether-anesthetized mice in ACD-A. Platelets were isolated by differential centrifugation at room temperature, first at 300 × g for 5 minutes to obtain platelet-rich plasma, which was then washed three times at 2,000 × g for 15 minutes. Contaminating red blood cells (RBCs) were removed by centrifugation at 100 × g for 5 minutes. Platelets (1 × 10<sup>7</sup>) were resuspended in 1 mL of ACD-A-saline (pH 7.6), to which 100 µL of <sup>111</sup>In-tropolone was added. The mixture was kept under constant agitation for 30 minutes at room temperature, and the radiolabeled platelets were then washed three times in ACD-A-saline and resuspended in 1.0 mL of saline. The labeling indices ranged from 50% to 70%. Recipient mice were injected intravenously (IV) with the radiolabeled platelets (3 to 5 µCi in 0.2 mL). Blood (15 µL) was taken 1 minute, 30 minutes, 1 hour, 2 hours, 4 hours, 24 hours, and 48 hours after injection. The radioactivity was counted using a well-typed scintillation counter (Aloka Co, Tokyo, Japan).

Data analysis. The mean platelet survival was estimated by calculating the rate of platelet disappearance from circulation using multiple-hit model analyses, as recommended by the International Committee for Standardization in Hematology. Platelet-associated antibodies. Because of the difficulty of obtaining sufficient blood samples, we used a modified method of platelet suspension immunofluorescence test (PSIFT) for PAA. Briefly, platelet suspensions were obtained from EDTA blood (30 µL) by centrifugation as mentioned above. After washing three times in 5 mmol/L EDTA-phosphate-buffered saline (PBS) (pH 6.8), the platelets were suspended in 1% paraformaldehyde solution for 5 minutes. Platelets were resuspended in 100 µL of EDTA-PBS to a platelet count of 3 × 10<sup>10</sup>/µL. Then they were incubated with 5 µL of FITC-conjugated goat anti-mouse immunoglobulin (Ig) (Becton Dickinson, Sunnyvale, CA) for 30 minutes at room temperature. After final washing, samples were analyzed on a FACScan (Becton

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were counted using a hematocytometer under a phase-contrast microscope. Platelet counts were analyzed to determine the highest level. Unlabeled platelets were first gated to exclude debris. Unlabeled platelets were first diluted in buffer containing ammonium oxalate (Unopette kits, Becton Dickinson). Platelets were counted using a hematocytometer under a phase-contrast microscope.

Platelet counts. Blood (20 μL) was diluted in buffer containing ammonium oxalate (Unopette kits, Becton Dickinson). Platelets were counted using a hematocytometer during the level of autofluorescence.

Table 1 summarizes the platelet counts, PAA values, and platelet survivals of variously aged W/B F1 mice. Male W/B F1 mice gradually showed thrombocytopenia with age, and a significant decrease in platelet counts was observed in mice aged more than 4 months. In contrast, the parent mice (NZW and BXSBI) and female W/B F1 (3 months) mice showed normal platelet counts, as did normal BALB/c mice. PAAs were positive in more than 2-month-old W/B F1 mice; percent-positive platelets increased with age (Table 1 and Fig 1). The mean platelet survival of BALB/c mice was 2.1 ± 1 days. Male W/B F1 mice more than 2 months of age showed significantly reduced PLS compared with male W/B F1 mice at the age of 1 month. As shown in Table 2, normal BALB/c mice; as did normal BALB/c mice.

RESULTS

Table 1. Platelet Lifespans, Platelet-Associated Antibodies, and Platelet Counts in W/B F1, Mice

<table>
<thead>
<tr>
<th>Mouse</th>
<th>Age (mo)</th>
<th>Sex</th>
<th>No.</th>
<th>Platelet Count (&lt;x; 10^3/μL)</th>
<th>PAA* (%)</th>
<th>Platelet Lifespan† (d)</th>
</tr>
</thead>
<tbody>
<tr>
<td>BALB/c</td>
<td>6</td>
<td>M</td>
<td>6</td>
<td>1,225 ± 153</td>
<td>1.6 ± 1.0</td>
<td>2.11 ± 0.28</td>
</tr>
<tr>
<td>NZW</td>
<td>6</td>
<td>M</td>
<td>5</td>
<td>1,006 ± 113</td>
<td>1.6 ± 0.9</td>
<td>1.62 ± 0.61</td>
</tr>
<tr>
<td>BXSBI</td>
<td>4</td>
<td>F</td>
<td>5</td>
<td>962 ± 91</td>
<td>1.9 ± 0.5</td>
<td>1.57 ± 0.33</td>
</tr>
<tr>
<td>W/B F1</td>
<td>3</td>
<td>F</td>
<td>3</td>
<td>1,012 ± 55</td>
<td>3.0 ± 2.4</td>
<td>1.44 ± 0.21</td>
</tr>
<tr>
<td>W/B F1</td>
<td>1</td>
<td>M</td>
<td>4</td>
<td>1,063 ± 114</td>
<td>1.4 ± 1.2</td>
<td>1.20 ± 0.40</td>
</tr>
<tr>
<td>W/B F1</td>
<td>2</td>
<td>M</td>
<td>4</td>
<td>1,021 ± 140</td>
<td>10.1 ± 6.1</td>
<td>0.56 ± 0.04‡</td>
</tr>
<tr>
<td>W/B F1</td>
<td>3</td>
<td>M</td>
<td>4</td>
<td>842 ± 67</td>
<td>18.9 ± 15.0</td>
<td>0.25 ± 0.11†</td>
</tr>
<tr>
<td>W/B F1</td>
<td>4</td>
<td>M</td>
<td>4</td>
<td>612 ± 104‡</td>
<td>15.9 ± 5.8‡</td>
<td>0.09 ± 0.03‡</td>
</tr>
<tr>
<td>W/B F1</td>
<td>5</td>
<td>M</td>
<td>4</td>
<td>502 ± 93‡</td>
<td>25.5 ± 4.6‡</td>
<td>0.12 ± 0.03‡</td>
</tr>
<tr>
<td>W/B F1</td>
<td>6</td>
<td>M</td>
<td>4</td>
<td>491 ± 72‡</td>
<td>49.9 ± 5.2‡</td>
<td>0.11 ± 0.04‡</td>
</tr>
</tbody>
</table>

*Platelets were labeled with FITC-conjugated goat anti-mouse Ig and analyzed using a FACScan.
†Platelet lifespan was examined by transferring 111In-labeled platelets from donor mice to age-matched mice of the same strain.
‡P<.001 versus data in young (1 month) F1 mice.

Dickinson) by gating to exclude debris. Unlabeled platelets were first analyzed to determine the highest level of autofluorescence, and then the percentage of positive platelets was calculated from the total platelet count above the level of autofluorescence.

Fig 1. Correlations between increased PAA values (O—O) and either reduced PLS (G—G) or decreased platelet counts (O—O) in male W/B F1 mice. N values for the individual points are shown in Table 1.

Fig 2. Relationships between age and platelet counts, PAA values, and PLS in male W/B F1 mice.
from male W/B F₁ mice (6 months) to BALB/c mice (6 months) were also cleared from circulation immediately (0.11 ± 0.02 days). Platelets transferred from male W/B F₁ mice (6 months) to female W/B F₁ mice (3 months) were also cleared from circulation immediately (0.12 ± 0.04 days).

**DISCUSSION**

In this study, we demonstrate that male W/B F₁ mice develop thrombocytopenia, increased anti-platelet antibodies on their platelet surface, and reduced platelet lifespans with age. There were statistically significant correlations between the increased PAA values and either the reduced PLS or the decreased platelet counts. From the present results and our previous findings of megakaryocytosis in the bone marrow, we consider that the mechanism of thrombocytopenia in male W/B F₁ mice is due to increased PAAs resulting in the acceleration of platelet destruction, but not to decreased platelet production.

W/B F₁ mice are well-known for developing systemic lupus erythematosus (SLE)-like diseases and their expression of high levels of circulating immune complexes (CICs). CIC-mediated thrombocytopenia was also demonstrated in patients with SLE. Moreover, it is known that the CICs bind to specific glycoproteins in some drug-induced thrombocytopenia. Although murine platelets have no Fc receptor, they possess C3b receptors capable of binding to CICs. It is conceivable that CICs are involved in the reduced PLS in these mice. However, other typical SLE-prone mice, such as NZB, MRL/1pr, and BXSB, which show high CIC levels, have normal platelet counts. Furthermore, the sera from BXSB and MRL/1pr mice do not bind to the platelets of BALB/c. From these results, it seems unlikely that increased PAAs in W/B F₁ mice are due to the binding of CICs to the platelet surface. Therefore, we think that CICs do not play an important role in platelet destruction in W/B F₁ mice. In fact, CICs are often observed in patients with ITP, but it is known that they have little influence on platelet destruction.

Significantly reduced PLS and increased PAA values were noted in male W/B F₁ mice even at the age of 2 months, although their platelet counts were almost normal. We speculate that platelet destruction was mild and compensated for by increased production of platelets in these mice of that age. Similar kinetic observations have also been reported in patients with ITP after splenectomy.

The immediate clearance of female W/B F₁ and normal BALB/c platelets transferred to male W/B F₁ mice indicates the presence of circulating anti-platelet antibodies in the plasma of old male W/B F₁ mice, as we previously demonstrated. Furthermore, old male W/B F₁ mouse platelets transferred to BALB/c mice were also cleared from circulation immediately. As shown in Fig 2, the significant correlations between the increase in PAA values and the decrease in PLS or platelet counts strongly suggest that the immediate clearance of transferred platelets is due to the presence of antibodies (PAAs and circulating anti-platelet antibodies), but not due to an abnormal host environment, such as hyperfunction of the reticuloendothelial system in old male W/B F₁ mice.

We have no data to show conclusively the presence of autoantibodies to platelets. We are not only in the process of verifying to which platelet epitopes antibodies are produced, but also clarifying where and how the platelets of W/B F₁ mice are destroyed.

Because the mechanism of thrombocytopenia observed here appears similar to that of human ITP, this animal could serve as a useful model for investigating the effectiveness and mode of action of new therapeutic agents in human ITP.

**REFERENCES**


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