An Animal Model of Allogeneic Donor Platelet Refractoriness: The Effect of the Time of Leukodepletion

By Morris A. Blajchman, Leslie Bardossy, Raleigh A. Carmen, Mindy Goldman, Nancy M. Heddle, and Dharam P. Singal

Approximately 50% of multi-transfused individuals become refractory to random donor platelets. Recent clinical data suggest that those patients receiving leukocyte-depleted blood products are less likely to become refractory to random donor platelets than recipients of non-leukocyte-depleted products. Leukocyte depletion can be performed immediately after collection of a unit of whole blood before its storage (prestorage leukodepletion) or just before the transfusion of the blood product to a recipient, after its storage (poststorage leukodepletion). However, the most appropriate time for the leukodepletion of blood products has not been established. The present study was undertaken to establish an animal model of allogeneic platelet refractoriness, and to compare the effect of prestorage and poststorage leukodepletion on the frequency of refractoriness to allogeneic donor platelets. In this model, two strains of rabbits were used: California Black rabbits were used as blood donors, while New Zealand White rabbits were used as recipients. Eight weekly infusions of nonleukodepleted allogeneic fresh blood resulted in an allogeneic platelet refractoriness rate of 91.2% (31/34). The prestorage leukodepletion of the donor blood was associated with a significantly higher allogeneic platelet survival and lower refractory rate (33.3%) to allogeneic platelets than poststorage leukodepletion (66.7%). Furthermore, the data suggest that cell-free plasma products are capable of inducing refractoriness to allogeneic donor platelets; the stored plasma having a greater likelihood of inducing such refractoriness than fresh plasma. Thus, these data provide evidence that the prestorage leukodepletion of allogeneic donor blood is associated with a lower frequency of refractoriness and better allogeneic platelet survival than poststorage leukodepletion.

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**Materials and Methods**

Animal model to study refractoriness to allogeneic donor platelets. Two different strains of outbred rabbits were used for these studies. The blood donors were California Black (CB) rabbits weighing 2.5 to 3.5 kg; New Zealand White (NZW) rabbits, also weighing 2.5 to 3.5 kg, were the recipients. The rabbits were purchased by the Animal Care Facility at McMaster University Medical Centre. Only male animals were used in all experiments to avoid the potential confounding problem of alloimmunization due to pregnancy. Blood was collected from at least 10 CB rabbits using

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the main auricular artery, 15 mL from each rabbit into CPD (7 vol whole blood to 1 vol CPD). Blood from each animal was pooled, mixed, and then 15-mL aliquots were transfused via a marginal ear vein to recipient NZW animals. After either 4 or 8 weeks of allogeneic whole blood transfusions, from the same donors, a platelet survival estimate was performed on each recipient animal using pooled fresh \(^{31}C\)-labeled platelets from CB rabbits as previously described.\(^{18}\) The platelet survival time for each recipient animal was calculated using a standard-assisted computer technique that determined, by the least-squares method, the mean platelet survival as a \(\gamma\)-function. The platelet survival time results were compared with that of a retrospective group of 26 nontransfused NZW male rabbits that had a mean survival time of fresh pooled platelets of 58.5 hours (SD 8.3 hours).\(^{19}\)

**Leukodepletion of fresh blood.** Whole blood was collected, as described above, from at least 10 CB rabbits. Fresh whole blood was pooled, mixed, and divided into two aliquots. One aliquot was leukodepleted using a second-generation leukocyte-depletion system (Leukotrap Red Cell Storage System; Cutter Biological, Berkeley, CA) providing at least 2 log (99.5%) leukodepletion.\(^{17,20}\) The other aliquot was not leukodepleted. Groups of 10 recipient NZW animals were transfused weekly, for 8 weeks with either 15 mL of the leukodepleted or 15 mL of nonleukodepleted fresh whole blood. After 8 weeks, platelet survival times were determined for both groups of recipient NZW rabbits using fresh CB rabbit \(^{31}C\)-labeled platelets from the same pool of donor animals.\(^{18}\)

**Prestorage leukodepletion versus poststorage leukodepletion.** Allogeneic (CB) rabbit donor blood was collected weekly into CPD for 8 weeks from at least 10 CB rabbits as described above. The blood was pooled and divided into two aliquots. One aliquot was leukodepleted before storage (prestorage leukodepletion) using the second-generation leukocyte-depletion system described above and then stored at 4°C for 1 week. The other aliquot was stored for 1 week at 4°C and then leukodepleted (poststorage leukodepletion) using a standard leukocyte-depletion filter (Sepacell R-500; Asahi Medical Co Ltd, Tokyo, Japan). Prestorage and poststorage leukodepleted allogeneic blood was transfused weekly to recipient NZW rabbits for 8 weeks. After 8 weeks, platelet survival times were determined in both groups of recipient NZW rabbits using the approach described above.

**Effect of the transfusion of fresh or stored allogeneic plasma.** CB rabbit blood was collected weekly into CPD for 8 weeks, from at least 10 CB rabbits as described above. The blood was pooled and divided into two aliquots. One aliquot was leukodepleted before storage, as described above, and the supernatant plasma removed and frozen at \(-30^\circ\)C until used. The other aliquot was stored for 1 week at 4°C, then leukodepleted following removal of the supernatant plasma and then frozen until used. The supernatant plasmas from both aliquots were thawed, refrozen and thawed again, before their administration to two groups of recipient NZW rabbits. The second refreezing and thawing was performed to ensure that no intact leukocytes remained in the plasmas. One group of NZW rabbits (n = 12) was transfused weekly with fresh frozen-thawed allogeneic plasma, and the other (n = 18) with stored frozen-thawed allogeneic plasma. No leukocytes were detectable in either aliquot of plasma. After eight weekly infusions of plasma to each recipient rabbit, allogeneic platelet survival times were estimated in each of the recipient rabbit groups, using the approach described above.\(^{18}\)

**Detection of lymphocytotoxic and platelet-related alloantibodies.** The presence of lymphocytotoxic antibodies to CB rabbit lymphocytes in the sera of transfused NZW rabbits was explored using a standard complement-mediated technique,\(^{21}\) except that CB rabbit lymphocytes were used instead of human lymphocytes. The presence of alloantibodies to CB rabbit platelet alloantigens was explored using a previously described platelet radioimmunoprecipitation technique.\(^{22}\)

**Hematologic techniques and statistical analyses used.** All leukocyte counts were performed microscopically using the Hauser counting chamber.\(^{23}\) The changes in leukocyte number, during the storage of the whole blood, were estimated on pooled blood obtained from at least 10 CB rabbits. Estimations were done on at least 15 different samples of stored blood (on days 0, 4, and 7 of storage) that had not been leukodepleted. Similarly, leukocyte enumeration was performed after leukodepletion. Statistical analyses were performed by comparing the mean platelet survival time of the different groups of rabbits using the nonpaired \(t\)-test, at a primary significance level of .05 (two-tailed). Differences between proportions were analyzed using a one-tailed chi-square test, or the Fisher's exact test. Confidence intervals (95%) were calculated on means and proportions.\(^{25}\)

**RESULTS**

**Allogeneic platelet survival time and refractory rate in recipient NZW rabbits receiving nonleukodepleted allogeneic whole blood.** The mean platelet survival (\(\gamma\)-function) time in the retrospective group of 26 normal NZW animals was 58.5 hours. The normal range (mean ± 2 SD) was 41.9 to 75.1 hours. Allogeneic (CB) platelet survival times of less than 41.9 hours, in the NZW recipient rabbits that had received allogeneic blood transfusions, were therefore considered to represent decreased platelet survival associated with the refractory state. The group of 10 recipient NZW rabbits that received four weekly transfusions of whole blood had a refractory rate of 50% with a mean platelet survival time of 30.4 hours, whereas the 34 NZW recipient rabbits had been transfused weekly for 8 weeks had a refractory rate of 91.2%, with a mean platelet survival time of 22.3 hours (SD 16.1 hours). The refractory rate in the rabbits transfused for 8 weeks is statistically greater than for the rabbits that had been transfused for only 4 weeks (\(P = .0001\)).

**Effect of leukodepletion of allogeneic blood on the platelet survival time and refractory rate of allogeneic donor platelets.** The platelet survival times and the refractory rates in NZW recipient rabbits that were transfused with either leukodepleted or nonleukodepleted allogeneic fresh whole blood weekly for 8 weeks are shown in Table 1. Rabbioths that had received leukodepleted allogeneic blood had a mean platelet survival time of 52.8 hours, whereas rabbits that had received nonleukodepleted allogeneic whole blood had a mean platelet survival time of only 22.3 hours (\(P = .0001\)). The refractory rate is also statistically different (\(P = .0003\)).

**Table 1. Platelet Survival and Refractory Rate of Allogeneic Rabbit (CB) Platelets in Recipient NZW Rabbits Receiving Either Leukodepleted or Nonleukodepleted Fresh Blood Weekly for Eight Weeks**

<table>
<thead>
<tr>
<th>Donor Blood Received</th>
<th>Mean Platelet Survival (95% CI)*</th>
<th>Refractory Rate (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Leukodepleted</td>
<td>52.8 h (SD 18.2 h)</td>
<td>30</td>
</tr>
<tr>
<td></td>
<td>(39.8-65.8 h)</td>
<td></td>
</tr>
<tr>
<td>Nonleukodepleted</td>
<td>22.3 h (SD 16.1 h)</td>
<td>91.2</td>
</tr>
<tr>
<td></td>
<td>(16.7-27.9 h)</td>
<td></td>
</tr>
</tbody>
</table>

*CI, confidence intervals. SD, standard deviation.
in these two groups of recipient animals, with a refractory rate of 30% in NZW recipient rabbits that had received leukodepleted blood and 91.2% in NZW animals that had received nonleukodepleted blood.

Effect of prestorage versus poststorage leukodepletion on refractoriness to allogeneic donor platelets. The leukocyte depletion of the transfused blood in these two groups of rabbits was similar; prestorage leukodepletion produced 99.5% leukodepletion (mean leukocyte count reduction: 6.738 to 0.034 \times 10^9/L) and poststorage leukodepletion was 99.6% effective (mean leukocyte count reduction: 5.328 to 0.022 \times 10^9/L). The numbers given are the means of 15 determinations in each category. Therefore, the two groups of animals received blood that was equivalent both in terms of leukodepletion and in terms of storage period. Allogeneic donor platelet mean survival time and refractory rates of leukodepletion and in terms of storage period. Allogeneic donor platelet mean survival time and refractory rates in recipient NZW rabbits that had received either prestorage or poststorage leukodepleted blood are shown in Table 2. The mean platelet survival time in these two groups of rabbits is statistically different \((P = .001)\). Animals that had received blood that had been leukodepleted prestorage had a mean platelet survival time of 54.7 hours as compared with the mean platelet survival time of 31.0 hours in NZW rabbits that had received poststorage leukodepleted blood. NZW rabbits that received prestorage leukodepleted blood had a refractory rate of 33.3% compared with a 66.7% refractory rate in rabbits that received poststorage leukodepleted blood \((P = .03)\).

Changes in the leukocyte count during storage. Table 3 shows the changes in the leukocyte count during the storage of rabbit whole blood in CPD for 1 week. After 7 days, the leukocyte counts dropped by 20.9%.

Effect of the transfusion of fresh and stored allogeneic plasma. Recipient NZW rabbits were infused for 8 weeks with either allogeneic cell-free fresh plasma \((n = 12)\) or allogeneic stored plasma that had been depleted of leukocytes after storage as whole blood at 4°C for 1 week \((n = 18)\). Allogeneic donor platelet survival times and refractory rates in these groups of rabbits were then determined and the results are summarized in Table 4. The mean platelet survival time of allogeneic platelets was 56.1 hours in the group of rabbits that received fresh plasma and 40.1 hours in the group that received stored plasma. The mean platelet survival times in these two groups is statistically significantly different \((P = .004)\). The refractory rates of 16.7% in the recipients of fresh plasma is also statistically different \((P = .02)\) from the refractory rate of 61.1% in the group that received stored plasma.

### Table 2. Platelet Survival and Refractory Rate of Allogeneic (CB) Platelets in Recipient NZW Rabbits That Had Received Either Fresh Plasma or Stored Plasma Weekly for Eight Weeks

<table>
<thead>
<tr>
<th>Leukodepletion Process</th>
<th>Mean Platelet Survival (95% CI)</th>
<th>Refractory Rate (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Prestorage</td>
<td>54.7 h (SD 20.6) (43.3-66.1 h)</td>
<td>33.3</td>
</tr>
<tr>
<td>Poststorage</td>
<td>31.0 h (SD 14.4) (23.1-39.0 h)</td>
<td>66.7</td>
</tr>
</tbody>
</table>

### Table 3. Changes in Leukocyte Counts During the Storage of CB Rabbit Whole Blood \((n = 15)\) for One Week

<table>
<thead>
<tr>
<th>Blood Storage Time (d)</th>
<th>Mean Leukocyte Count (\times 10^9)/mL (95% CI)</th>
<th>% Reduction in Leukocyte Count</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>6.74 (SD 0.80) (6.3-7.2)</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>6.24 (SD 0.93) (5.7-6.8)</td>
<td>7.4</td>
</tr>
<tr>
<td>7</td>
<td>5.33 (SD 0.94) (4.8-5.9)</td>
<td>20.9</td>
</tr>
</tbody>
</table>

### Table 4. Platelet Survival and Refractory Rate of Allogeneic Platelets in Recipient NZB Rabbits That Had Received Either Fresh Plasma or Stored Plasma Weekly for Eight Weeks

<table>
<thead>
<tr>
<th>Product Transfused</th>
<th>Mean Platelet Survival (95% CI)</th>
<th>Refractory Rate (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fresh plasma</td>
<td>56.1 h (SD 13.8) (47.4-64.9 h)</td>
<td>16.7</td>
</tr>
<tr>
<td>Stored plasma</td>
<td>40.1 h (SD 13.4) (33.4-46.7 h)</td>
<td>61.1</td>
</tr>
</tbody>
</table>

Detection of lymphocytotoxic and platelet-related alloantibodies. Lymphocytotoxic antibodies to CB rabbit lymphocytes could be demonstrated in the serum of only 1 of 31 refractory NZW rabbits tested. None of 16 nonrefractory animals tested provided any evidence of lymphocytotoxic antibodies to CB rabbit lymphocytes. Using the platelet radioimmunoprecipitation technique, the sera of 12 of 31 refractory NZW animals were shown to contain antibodies to CB rabbit platelet antigens. None of the sera of the 16 nonrefractory animals tested positive for the presence of antibodies to CB rabbit platelet antigens. This difference in platelet antibody incidence between refractory and nonrefractory animals is statistically significant \((P = .004)\).

**DISCUSSION**

The available clinical data in humans suggests that the leukodepletion of blood products is effective in reducing the rate of refractoriness to random donor platelets.\(^5\)\(^6\) However, many questions regarding leukodepletion remain unanswered.\(^6\)\(^5\)\(^16\) One unanswered question is whether the leukodepletion should be performed before storage (prestorage leukodepletion) or just before transfusion after storage (poststorage leukodepletion). The results from these animal studies clearly demonstrate that most recipient animals become refractory to allogeneic platelets after eight weekly transfusions of allogeneic whole blood. The refractory rate in recipient NZW rabbits was somewhat dependent on the amount of blood transfused. Animals transfused with allogeneic blood for 8 weeks had a refractory rate of 91.2%, whereas those transfused for 4 weeks had a refractory rate of 50%. The latter refractory rate is similar to that seen in humans; however, for the purposes of examining the effect of the various parameters of leukodepletion, we used recipient animals that were transfused for 8 weeks. This was done to maximize the frequency of the refractory rate, and thus maximize the effect of the leukodepletion. Thus, we were able to provide data that clearly demonstrate that the leukodepletion of allogeneic fresh whole blood significantly reduces the frequency of allogeneic donor platelet refractoriness and increases their in vivo survival. Furthermore, the
present results show clearly that the prestorage leukodepletion of allogeneic donor blood is associated with a reduced frequency of allogeneic platelet refractoriness and a higher in vivo survival, compared with poststorage leukodepletion.

Little is known about the major histocompatibility complex (MHC) in rabbits. Furthermore, both strains of rabbits used in the present study are outbred. For this reason we transfused pooled allogeneic blood to recipient animals. The amount of blood infused weekly (15 mL) represents the equivalent of approximately 1 U of whole blood infused into an adult human. To partially validate our animal model, we were able to demonstrate that changes in allogeneic platelet survival correlated somewhat with the development of specific platelet or lymphocytotoxic antibodies in recipient animals who became refractory to allogeneic donor platelets. We used two different approaches to ascertain the presence of antibodies. Using the complement-mediated lymphocytotoxicity test,21 antibodies to CB rabbit lymphocytes could be demonstrated in only 1 of 31 refractory animals tested. Using the platelet radioimmunoprecipitation technique22; the sera of 12 of 31 recipient animals that were refractory to allogeneic donor platelets were shown to contain antibodies to allogeneic platelet antigens. In none of the sera of 16 nonrefractory animals tested could we demonstrate the presence of antibody using either technique. Thus, the incidence of antibodies in refractory rabbits was significantly higher \((P = .004)\) than in nonrefractory animals. Further characterization of these antibodies is in progress. Nonetheless, these preliminary antibody data suggest that the incidence of antibody positivity reflects the technique used, similar to that seen in humans, and also that the refractory state in recipient animals is immune mediated.

The present data indicate that during the storage of rabbit whole blood for 1 week the leukocyte count decreases by over 20%. These results are essentially similar to those observed during the storage of human blood.23,24 Thus, these data suggest that leukocytes can release soluble antigens, or microparticles containing antigens, into the plasma during storage and that these antigens escape leukodepletion. Similarly, HLA antigens have been demonstrated in stored human plasma.25 The data obtained in this study, with the transfusion of poststorage leukodepleted blood, are consistent with this hypothesis. Furthermore, the results obtained from the groups of rabbits that received allogeneic plasma infusions suggest that refractoriness to allogeneic platelets may be induced by non-intact leukocytes.

To our knowledge this is the first demonstration of the advantages of the prestorage leukodepletion of blood products over poststorage leukodepletion. However, data from animal experiments cannot necessarily be extrapolated to the human situation. Therefore, we recommend that properly designed prospective, randomized clinical studies be conducted to ascertain whether the superiority of prestorage leukodepletion over poststorage leukodepletion is also true for humans.

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