Heparin-Associated Thrombocytopenia: Antibody Binding Specificity to Platelet Antigens

By Dona M. Lynch and Stephen E. Howe

Sera from four patients with heparin-associated thrombocytopenia (HAT) were evaluated by a quantitative enzyme-linked immunosorbent assay (ELISA) to detect heparin-dependent serum platelet-bindable immunoglobulin (S-PBIg) and by Western blotting and immunoprecipitation to investigate the specificity of the antibody binding. All HAT sera showed mildly increased S-PBIg (mean, 7.8 fg per platelet; normal, <6.0 fg per platelet) to intact target platelets in the ELISA, which was markedly increased in the presence of heparin (mean, 20.9 fg per platelet). This increase was 20-fold greater than normal control sera, which showed a mean differential increase of only 0.5 fg per platelet. Immunoglobulin binding specificity to platelet antigens was investigated using sodium dodecyl sulfate-polyacrylamide gel electrophoresis of platelet lysate with transfer of the platelet fractions onto nitrocellulose strips (Western blotting) and subsequent immunoprecipitation to platelet proteins of the same apparent molecular weights. These observations are consistent with current hypotheses suggesting that HAT antibody is directed to heparin–platelet complexes or, alternatively, that heparin induces conformational change of antigenic sites on the platelet membrane.

Platelet Antibody has been demonstrated in patients with heparin-associated thrombocytopenia (HAT). In the presence of exogenous heparin, immunoglobulin in HAT sera binds to platelets and may induce platelet aggregation and release. Several theoretical models have been proposed to describe the clinical syndrome and immunologic mechanism; however, the interaction and binding specificities of HAT antibody and heparin to platelet membrane antigen have remained obscure. In this study, the quantitative binding of HAT antibody to platelet surface was determined using an enzyme-linked immunosorbent assay (ELISA) procedure. The binding specificities of the antibody and heparin to platelet fractions were investigated using Western blotting and immunoprecipitation.

MATERIALS AND METHODS

Patients and control groups. Group 1 consisted of four patients with severe delayed HAT. Medical histories included a normal platelet count (150,000 to 400,000 platelets per microliter) prior to heparin therapy, a decrease in platelet count below 80,000 per microliter during heparin administration, an increase in platelet count within ten days after discontinuing heparin administration, and the exclusion of other causes of thrombocytopenia.

Group 2 consisted of 13 normal nonthrombocytopenic volunteers. Group 3 consisted of ten nonthrombocytopenic patients one week after intravenous (IV) heparin therapy.

Group 4 consisted of ten patients with autoimmune thrombocytopenic purpura (ATP) following the criteria of Lacey and Pennner.

Group 5 consisted of ten patients with nonimmune thrombocytopenia (4,000 to 60,000 per microliter) attributed to lymphoma, chemotherapy, sepsis, leukemia, or increased peripheral platelet destruction.

Specimens. Patients were evaluated after we obtained informed consent in accordance with our institution's Committee on Human Experimentation. Specimens consisted of serum or plasma obtained by venipuncture using siliconized clot tubes or 0.11 mol/L sodium citrate (Becton Dickinson Vacutainer Systems, Rutherford, NJ). At the time the sera were obtained, no patients in these groups were being treated with heparin. To prevent possible immunoglobulin loss, sera was not heat-inactivated to destroy residual thrombin. Whole blood was centrifuged at 1.200 g for ten minutes. Plasma and sera were separated, tested immediately, or stored frozen at ~70 °C. Sera were collected during the thrombocytopenic phase and prior to corticosteroid treatment in ATP patients. Platelet counts and routine coagulation values were obtained from the clinical laboratory. Heparin-induced platelet aggregations were performed independently in the clinical laboratory, as described by Kapsch and Silver.

All chemicals were purchased from Sigma Chemical Company (St. Louis) unless otherwise indicated.

ELISA for heparin-induced platelet-bindable immunoglobulin. A modification of an ELISA for serum platelet-bindable immunoglobulin (S-PBIg) was performed as previously described. Briefly, the assay was as follows: pooled human platelets were washed in phosphate-buffered saline (PBS) and fixed with 2% paraformaldehyde. These platelets were added in amounts of 10' cells to wells of a Nunc Immunoplate I (Vanguard International, Neptune, NJ) and centrifuged at 1,000 g for ten minutes to adhere the platelets to the wells. A standard curve was prepared with quantitated chromatographically purified human IgG (Cappel Laboratories, Malvern, Pa) and cells adsorbed to the plate wells overnight at room temperature to obtain maximum binding. All wells were “blocked” with 0.1% gelatin (Difco Laboratories, Detroit) in PBS–0.05% Tween-20 for 90 minutes at room temperature. The plates were washed twice with PBS–0.05% Tween-20 using a DynaPro SR Dispensor Unit (Dynatech Laboratories, Alexandria, Va). Triplicate aliquots of 100 μL of undiluted sera were added to microtiter wells as follows: (1) sera alone and (2) sera with 5 U/mL (final concentration) beef lung heparin (Organon, W Orange, NJ) coincubated in the wells. (Beef lung heparin was selected for use in this assay, as it provided the most pronounced platelet aggregations in the two patients positive for heparin-induced platelet aggregations.) The ELISA plate was incubated for 60 minutes at 37 °C, drained, bloated, and incubated with PBS–Twee–gelatin for ten minutes. The gelatin incubation was followed...
by three washes with PBS-Tween. Optimally titrated (1:500) horse radish peroxidase-conjugated goat F(ab')2 anti-human immunoglobulin (Cappel), in 100–µL volumes, was added to all wells and incubated at room temperature for 90 minutes, followed by a ten-minute PBS-Tween-gelatin incubation and two washes with PBS-Tween. OPD substrate (40 mg o-phenylenediamine dihydrochloride dissolved in 100 mL of phosphate citrate buffer [24.3 mL of 0.1 mol/L citric acid, 25.7 mL of 0.2 mol/L Na3PO4, 50 mL of H2O], 0.15 mL of 30% H2O2 added prior to use) was added in 100-µL amounts of each well. Color development was terminated at 20 minutes with the addition of 100 µL of 0.2 mol/L H2SO4, and the absorbance was read at 490 nm with an EIA Reader (Bio-tek, Burlington, VT). S-PBlg in femtograms per platelet was calculated by using previously standardized binding percentages of the platelets and standards. In the lot of microtiter plates tested, 1.4 × 10⁶ platelets remained in the well at the conclusion of the assay. After incubation with patient sera, absorbances were compared to a standard reference curve to obtain nanograms of Ig per well. This reaction was terminated with a tap water wash and the strips were allowed to dry in the dark.

Immunoprecipitation. Immunoprecipitation was performed using a modification of the method of Chong et al. Fresh washed platelets were surface-labeled with 125I by the iodogen method described. After dialysis, the labeled platelets were resuspended in 5 × 10⁶ per milliliter in PBS with 0.2 mmol/L EGTA. To this suspension 200 µg/mL leupeptin and 0.5 mmol/L phenylmethylsulfonyl fluoride was added and solubilized with a final concentration of 2% (vol/vol) Triton X-100 (Bio-Rad). The solubilized surface-labeled platelets were centrifuged at 1,200 g for ten minutes to sediment the insoluble platelet fractions. A 50-µL aliquot of solubilized platelets was added to 50 µL of patient serum with or without beef lung heparin (final concentration, 5 U/mL). The mixture was incubated at 37°C for 90 minutes. Following incubation, 50 µL of a 1% suspension of protein A-CB Sepharose (Pharmacia, Uppsala, Sweden), in PBS-EGTA with 1% Triton X-100, was added and allowed to equilibrate for 30 minutes at 4°C. The Sepharose sediment was washed two times with PBS-EGTA with 2% (wt/vol) bovine serum albumin, and once with PBS-EGTA alone, with centrifugation at 18,000 g for three minutes between washes. Following the last wash, the pellet was solubilized in 3% SDS sample buffer, boiling for ten minutes. The solubilized sample centrifuged as above and loaded into wells of an 8.5% SDS-PAGE slab gel, electrophoresis performed as described. The proteins were stained with Coomassie Brilliant Blue, the gels were dried, and autoradiography was performed.

Autoradiography. Nitrocellulose strips incubated with radiolabeled heparin and the dried immunoprecipitate gel were autoradiographed using X-Omat RP film (Eastman Kodak Company, Rochester, NY) with Cronex Lightening Plus intensifying screens (DuPont, Wilmington, Del) at −70°C for up to one month, depending on radioactivity levels.

RESULTS

Patients. Clinical data for the HAT patients are presented in Table 1. On admission, all HAT patients had normal platelet counts, which decreased to 12,000 to 70,000 per microliter after nine to 12 days of heparin therapy. Three patients developed pulmonary emboli while receiving heparin, and the fourth showed severe retroperitoneal hemorrhage. Prior to heparin therapy, all coagulation tests were abnormal. There was no evidence of disseminated intravascular coagulation, although the fibrin split products (FSPs) became slightly elevated in the three patients with pulmonary emboli and this was attributed to clot lysis. Two of four HAT serum samples aggregated test platelets when incubated with beef lung heparin. Plasma from patient 3 induced spontaneous platelet aggregation in the absence of exogenous heparin. The specimen tested was obtained three days after
cessation of heparin therapy. Although no active heparin was detected using a thrombin time assay, no attempt was made to exclude low levels of heparin not detected by this assay or the presence of inactive antigenic heparin.

**ELISA.** Four HAT patient serum samples, 13 normal control serum samples, and combined control groups (N = 43) were tested with and without heparin in the ELISA procedure. The results are presented in Table 2. All HAT patient sera demonstrated mildly elevated baseline S-PBIg (no heparin), with a mean value of 7.8 fg per platelet (normal, <6.0 fg per platelet). Coincubations of heparin, serum, and target platelets produced a markedly increased S-PBIg (no heparin), with a mean value of 7.8 fg per platelet, a differential increase of 168%. Normal control sera showed a mean increase of only 0.5 fg per platelet, a 16% differential increase. The increase demonstrated in the HAT group was 20-fold greater than that of the normal controls. To further evaluate this elevation of S-PBIg after heparin coincubations, we similarly tested ten patients with ATP, ten patients with nonimmune thrombocytopenia, and ten nonthrombocytopenic patients following therapeutic IV heparin therapy. For the combined control groups, there was only a relatively slight increase of 0.7 fg per platelet, or 1% above baseline S-PBIg with heparin coincubations (Fig 1).

**Western blot.** Western blots performed on four HAT serum samples in the presence of heparin showed increased binding of immunoglobin to platelet membrane antigens with apparent molecular weights of 180, 124, and 82 kd (Table 3). Representative nitrocellulose strips with and without heparin coincubations from one HAT patient and one normal control are presented in Fig 2. These platelet antigens were determined to be surface components by iodination of intact platelets. In general, as described in Table 3, there were low but detectable levels of immunoglobulin bound to these antigens in the absence of added exogenous heparin. However, in the presence of heparin, binding to these antigens was greatly enhanced, paralleling the ELISA results. Western blots performed on ten normal and ten ATP patients showed no enhancement of immunoglobulin binding to any platelet antigen with heparin coincubation.

**Autoradiography.** Binding of heparin to platelet fractions in the Western blot were studied using radiolabeled heparin. Nitrocellulose strips containing transferred platelet proteins were incubated with iodinated heparin and test sera. After Western blotting was completed with localization of precipitated immunoglobulin bands, these strips were autoradiographed. In the presence of HAT sera, normal control sera, and bovine serum albumin blank, 121I-labeled heparin bound most strongly to platelet fractions of approximate molecular weights of 180, 124, and 82 kd. The iodinated heparin bound to these antigens independent of immunoglobulin detected in the immunoperoxidase system. Heparin

### Table 1. Laboratory and Clinical Data for Patients With HAT

<table>
<thead>
<tr>
<th>Patient No.</th>
<th>No. of Platelets on Admission</th>
<th>Platelet Count</th>
<th>Onset of HAT*</th>
<th>Average Heparin†</th>
<th>PTT (s)</th>
<th>Fibrinogen (mg/dL)</th>
<th>FSP (µg/mL)</th>
<th>Aggregation Platelet</th>
<th>Complications</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>250,000</td>
<td>17,000</td>
<td>12</td>
<td>1,600</td>
<td>30</td>
<td>294</td>
<td>40–80</td>
<td>Positive</td>
<td>Pulmonary emboli‡</td>
</tr>
<tr>
<td>2</td>
<td>252,000</td>
<td>19,000</td>
<td>8</td>
<td>28,000</td>
<td>31</td>
<td>320</td>
<td>40–80</td>
<td>Positive</td>
<td>Pulmonary emboli‡</td>
</tr>
<tr>
<td>3</td>
<td>280,000</td>
<td>12,000</td>
<td>7</td>
<td>5,000</td>
<td>31</td>
<td>400</td>
<td>40–80</td>
<td>Spontaneous</td>
<td>Pulmonary emboli‡</td>
</tr>
<tr>
<td>4</td>
<td>Adequate§</td>
<td>70,000</td>
<td>9</td>
<td>3,000</td>
<td>26</td>
<td>190</td>
<td>&lt;10</td>
<td>Negative</td>
<td>Retropertioneal hemorrhage</td>
</tr>
</tbody>
</table>

* No. of days after heparin therapy was initiated.
† Average dose of heparin infused (U/d).
‡ Patient expired.
§ Admission slide was estimated to be adequate.

### Table 2. Comparison of S-PBIg From HAT, Normal, and Combined Control Sera Using an ELISA Platelet Antibody Procedure to Quantitate the Increase of Immunoglobulin Binding in the Presence of Heparin

<table>
<thead>
<tr>
<th></th>
<th>HAT*</th>
<th>Normal†</th>
<th>All Controls‡</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Base</td>
<td>Heparin§</td>
<td>Base</td>
</tr>
<tr>
<td>Mean</td>
<td>7.8</td>
<td>20.9</td>
<td>3.1</td>
</tr>
<tr>
<td>SD</td>
<td>2.1</td>
<td>9.6</td>
<td>1.3</td>
</tr>
<tr>
<td>SEM</td>
<td>1.2</td>
<td>5.5</td>
<td>0.4</td>
</tr>
<tr>
<td>Increase†</td>
<td>13.1</td>
<td>0.5</td>
<td>0.5</td>
</tr>
<tr>
<td>Range‡</td>
<td>(7.8–26.1)</td>
<td>(0.3–2.8)</td>
<td>(0.3–2.8)</td>
</tr>
</tbody>
</table>

Values are expressed as femtograms per platelet.
* Four HAT patient sera.
† Thirteen normal control sera.
‡ Forty-three patients in all control groups (see text).
§ Heparin co-incubations (5 U/mL, final concentration).
† Mean differential increase of S-PBIg with heparin over base.
‡ Range of differential increases seen in the groups.

**Fig 1.** Differential binding of S-PBIg from the platelet antibody ELISA in the absence (C) or presence (B) of heparin. The groups are: (1) four HAT patients, (2) 13 normal individuals, (3) ten non-thrombocytopenic patients after IV heparin therapy, (4) ten patients with autoimmune thrombocytopenia purpura, and (5) ten patients with nonimmune thrombocytopenia. Bars indicate the SEM.
Table 3. Antibodies From HAT Patients to Platelet Glycoproteins as Identified by Western Blotting

<table>
<thead>
<tr>
<th>Patient No.</th>
<th>Baseline Serum Bands</th>
<th>Heparin and Serum Bands</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>180</td>
<td>180++</td>
</tr>
<tr>
<td></td>
<td>124</td>
<td>124++</td>
</tr>
<tr>
<td></td>
<td>82</td>
<td>82++</td>
</tr>
<tr>
<td>2</td>
<td>180</td>
<td>180++</td>
</tr>
<tr>
<td></td>
<td>124</td>
<td>124++</td>
</tr>
<tr>
<td></td>
<td>82</td>
<td>82++</td>
</tr>
<tr>
<td></td>
<td>50</td>
<td>50</td>
</tr>
<tr>
<td>3</td>
<td>180</td>
<td>180+</td>
</tr>
<tr>
<td></td>
<td>124+</td>
<td>124++</td>
</tr>
<tr>
<td></td>
<td>82</td>
<td>82+</td>
</tr>
<tr>
<td>4</td>
<td>180</td>
<td>180+</td>
</tr>
<tr>
<td></td>
<td>124+</td>
<td>124++</td>
</tr>
<tr>
<td></td>
<td>82</td>
<td>82+</td>
</tr>
</tbody>
</table>

Values are expressed as apparent molecular weights (kilodaltons). +, increased or markedly increased antibody binding, respectively.

qualitatively appeared to bind strongest at the 180- and 82-kd fractions (Fig 3). The intensity of the bound labeled heparin did not necessarily correlate with the intensity of the bound immunoglobulin detected by Western blotting.

Immunoprecipitation of radiolabeled surface platelet components with heparin-enhanced platelet antibody. Immunoprecipitation of surface-labeled Triton X-100-solubilized platelets was performed with HAT, ATP, and normal sera using protein A bound to Sepharose. Precipitated fractions were electrophoresed and autoradiography was performed (Fig 4). Weak precipitation was demonstrated by the HAT sera of a protein fraction migrating at 82 kd, which appeared qualitatively to be enhanced in two HAT patients in the presence of added heparin. These bands were not precipitated by control sera. Following the albumin fraction at approximately 64 kd, a protein fraction was precipitated by HAT sera. This precipitated protein was not detected in the Western blotting procedure and may represent a product of proteolysis.

DISCUSSION

Immune mechanisms have been described by several investigators in studies of HAT. A variety of techniques have been used to demonstrate heparin-dependent platelet antibodies in HAT patients' sera. The classes of immunoglobulin identified in these studies have included IgG, IgM, and IgG–IgA, and the complement component C3. In the present study, sera from HAT patients and sera from four control groups were evaluated using an ELISA procedure to determine the effect...
detect significant immunoprecipitation of those determi-
and 82 kd. We were able to confirm only the antigenic
of heparin, all HAT patient sera showed the appearance
enhancement of immunoglobulin binding (Table 2). The
importance of additional exogenous heparin in the interac-
tion of the HAT antibody with platelet antigen was evident
in the 20-fold increase of bound immunoglobulin in the HAT
sera. A fainter band was also detected in the autoradiograph at approximately 145,000 daltons, which
was not detected in the patients with HAT syndrome. The binding of heparin 125I to specific platelet fractions occurred in the presence of HAT sera, control sera, and albumin blanks.

We have not attempted to specifically identify the platelet constituents migrating with apparent molecular weights of 180, 124, and 82 kd that complex with heparin and HAT antibodies. Several platelet components, both surface glyco-
proteins, and α-granule proteins have been reported to bind heparin. Alpha-granule proteins such as thrombospondin (TSP) may become surface-associated after release and could function as a surface antigen. Of the known heparin-binding platelet proteins, TSP, with a molecular weight of 180 kd, a digestion product of TSP at 120 kd, and glycoprotein V (thrombin substrate) at 80 kd are provocative candidates as antigen for HAT antibody. Possible involvement of the thrombin substrate may explain the strong association in HAT patients with irreversible platelet aggregation, thrombosis, and thrombocytopenia.

Various mechanisms of heparin interaction in immune-
mediated HAT have been proposed. Heparin has been suggested to function as a hapten, an antigen, a heparin–plasma protein complex, a platelet–heparin antigenic complex, or as an intermediate of an independent immune reaction. Although the data presented do not exclude theoretical models involving antibody directed to a hapten or heparin–platelet complex, the possibility of hepa-
in and platelet–protein interaction involving charge relationships and conformational change of antigenic binding sites is suggestive. In the absence of exogenous heparin, platelet-directed antibody was detected by ELISA, Western blotting, and immunoprecipitation in HAT patient sera. These observations suggest that the antigenic sites were present on platelets in the absence or with low concentration of heparin. Immune binding to these platelet proteins was greatly enhanced when heparin was added to the system. One mode of action postulated for highly negatively charged preparations such as heparin involves the alteration of the

![Fig 4. An autoradiograph of an immunoprecipitation assay utilizing 125I surface-labeled platelet lysate and HAT and normal sera with and without exogenously added heparin (5 U/mL final concentration of beef lung heparin). Lane 1 is dilute surface-labeled platelet lysate alone. Lane 2 is HAT serum with heparin. Lane 3 is HAT serum without heparin. Lanes 4 and 5 are normal serum with and without heparin, respectively. Indicated are the approximate molecular weight designations of precipitated surface-labeled platelet proteins.](image-url)
protein configuration of platelet membranes after binding, resulting in new antigenic sites, or making existing sites on the platelet surface more accessible. Although we did not test the effects of other polyglycosaminoglycans, Wolf and associates used heparin and the polysulfated glycosaminoglycan, Artepon, to compare the effect on platelet aggregation and platelet IgG binding when coincubated with suspected HAT sera. They found that heparin and Artepon caused platelet aggregation and positive indirect immunofluorescence reactions using whole IgG, F(ab')2, or Fe fractions from these patients. Singer and Nicholson’s fluid mosaic model for biological membranes is consistent with the theory of altered antigenic sites. With highly charged molecules such as heparin bound to one surface receptor, alteration of the binding kinetics of another receptor may occur due to the dynamic nature of the hydrophobic bilayer arrangement of phospholipids. By binding to opposite charges on the exposed platelet membrane proteins, heparin may induce conformational changes of antigenic sites and effectively expose or access a sequestered amino acid sequence recognized by the immune system of a patient with HAT.

ACKNOWLEDGMENT

We wish to express our gratitude to Dr Thomas Kloppe for his assistance with the techniques used for SDS-PAGE and Western blotting, to Dr W. Robert Adams for his support of this project, and to Dr James Lynch for theoretical discussions.

REFERENCES

7. Wahl TO, Lipschitz DA, Stechschulte DJ: Thrombocytopenia associated with antiheparin antibody. JAMA 240:8, 1984
Heparin-associated thrombocytopenia: antibody binding specificity to platelet antigens

DM Lynch and SE Howe