HEMOSTASIS, THROMBOSIS, AND VASCULAR BIOLOGY

Procoagulant Effect of Anti–β2-Glycoprotein I Antibodies With Lupus Anticoagulant Activity

By V. Pengo, T. Brocco, A. Biasiolo, P. Rampazzo, P. Carraro, and R. Zamarchi

Prothrombin time (PT) is routinely used to monitor oral anticoagulant treatment in patients with the antiphospholipid antibody syndrome (APS). The fact that PT is a phospholipid (PL)-dependent coagulation test raises the possibility that lupus anticoagulant (LA) might interfere with this test, thus complicating the control of anticoagulant treatment. The effect of 6 affinity-purified preparations of anti- (aβ2-GPI) antibodies with LA activity on PT was tested. Instead of prolonging PT as expected, the aβ2-GPI antibodies reduced the PT of both normal plasma and anticoagulated plasma by a mean of 2.4 seconds and 5.6 seconds, respectively. This effect was also observed using other 5 commercially available preparations of thromboplastin. The aβ2-GPI-mediated reduction in PT was dose-dependent and was lost upon removal of β2-GPI. The failure of aβ2-GPI antibodies to express LA activity in PT was found to depend on the fact that calcium ions were added together with PL at the beginning of the assay. In fact, modification of the standard diluted Russell viper venom time (dRVVT) test by adding calcium ions together with PL resulted in a loss of aβ2-GPI anticoagulant activity. The procoagulant effect was not as evident in an assay that used stimulated monocytes as a source of thromboplastin. These results show that aβ2-GPI antibodies exhibit an ‘in vitro’ procoagulant effect in PT and an anticoagulant effect in dRVVT only when the interaction with their antigen and PL occurs in the absence of calcium ions.

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The term ‘lupus anticoagulant’ (LA) defines a group of immunoglobulins able to prolong the clotting time of phospholipid (PL)-dependent coagulation tests.1 The interest in detecting LA is related to the fact that its presence is strongly associated with both arterial and venous thromboembolism.2,3 Ten years after demonstration of the antiphospholipid nature of these immunoglobulins in 1980,4 it was shown that autoimmune antiphospholipid (aPL) antibodies require the plasma protein β2-glycoprotein I (β2-GPI) to bind anionic PL.5-7 It was subsequently recognized that β2-GPI is essential for the expression of the LA activity of some aPL antibodies,8,9 and that its adsorption removes LA activity from most LA-positive plasma samples.10 Affinity-purified aβ2-GPI antibodies from plasma of LA-positive patients behave as classical LA, with their activity disappearing at increasing PL concentrations.11 Moreover, some monoclonal antibodies to β2-GPI express LA activity,12,13 depending on the specific domain against which they are directed.12 The mechanism underlying LA activity of aβ2-GPI antibodies is related to their ability to enhance binding of β2-GPI to PL, thus impeding binding/activation of clotting factors.12

As suggested by the Scientific and Standardization Committee of the International Society on Thrombosis and Haemostasis,14 the laboratory diagnosis of LA requires the prolongation of at least one PL-dependent coagulation test, and the demonstra-
fied αβ2-GPI antibodies and control IgG were tested after a 1:4 dilution in αβ2-GPI IgG ELISA as previously described. Preparations of αβ2-GPI-depleted plasma. Pooled normal plasma was passed through a CL-6B Sepharose column as previously reported. To estimate the quantity of residual β2-GPI in the flow through, 24-µL samples (diluted 1:2 in 20 mmol/L Tris, 150 mmol/L NaCl, pH 7.4 [TBS]) were applied to 4.0-mm wells of a 1% agarose gel containing 6% vol/vol polyonal αβ2-GPI rabbit antiserum, and subjected to single radial immunodiffusion. Purified β2-GPI was serially diluted with TBS, pH 7.4, and analyzed in parallel to provide a calibration curve. Results of this analysis showed that β2-GPI was no longer detectable in the depleted plasma.

Coagulation studies. Pooled plasma from 5 healthy subjects and pooled plasma from 5 patients on stable oral anticoagulant treatment were used as coagulation substrates. Clotting times were recorded using an automated fibrometer (Mechrolab Clot-timer Model 202A; Heller Laboratories, Santa Rosa, CA). LA activity of purified αβ2-GPI IgG preparations was evaluated by dRVVT as previously described. Standard PT was assayed by preincubating 100 µL of plasma at 37°C for 2 minutes, followed by the addition of 200 µL of calcium thromboplastin. In experiments performed to test the importance of the sequence of reagent addition, tissue thromboplastin was incubated with αβ2-GPI antibodies in the presence or absence of calcium ions for 2 minutes before addition of anticoagulated plasma. In some experiments, the reconstituted Recombiplastin was further diluted with 30 mmol/L CaCl₂.

A modified dRVVT was performed by changing the sequence of added reagents. In the dRVVT used to measure the LA activity of purified antibodies, the addition sequence was (1) normal plasma; (2) TBS, normal IgG, or affinity-purified αβ2-GPI IgG; (3) viper venom; (4) PL, followed by incubation at 37°C for 30 seconds; and (5) CaCl₂, followed by measurement of clotting time. In a modified test the sequence was (1), (2), and (3), followed by the addition of CaCl₂ and PL of concentrated calcium thromboplastin. In experiments performed to test the importance of the sequence of reagent addition, tissue thromboplastin was incubated with αβ2-GPI antibodies for 2 minutes before addition of anticoagulated plasma. In some experiments, the reconstituted Recombiplastin was further diluted with 30 mmol/L CaCl₂.

Results

Affinity-purified preparations of αβ2-GPI IgG antibodies were obtained from plasma samples of 6 patients with APS. All 6 preparations showed LA activity in dRVVT, with prolongation of clotting time ranging from 3.7 to 8.3 seconds over control IgG. All 6 preparations also showed marked positivity in αβ2-GPI IgG ELISA, with the OD₄₅₀ ranging from 2.587 U for patient no. 5 to 3.492 U for patient no. 1 (Table 1). These preparations were then tested by PT (see Materials and Methods) with the thromboplastin routinely used in our laboratory (Recombiplastin) and pooled normal plasma as a substrate. Comparison of results obtained with normal IgG showed that all of the αβ2-GPI antibody preparations slightly shortened the PT, with the reduction ranging from 1.1 seconds in patient no. 5 to 2.9 seconds in patient no. 2 (mean, 2.4 seconds) (Fig 1). As shown in Fig 2, this procoagulant effect was also observed in assays performed using pooled plasma from 5 patients on stable long-term anticoagulant treatment (International Normalized Ratio [INR] of pooled plasma was 2.28). Compared with normal IgG, the αβ2-GPI antibody preparations shortened the PT of the anticoagulated pool by a mean of 5.6 seconds (from a minimum of 4.5 seconds in patient no. 5 to a maximum of 6.7 seconds in patient no. 6). Results were comparable when using different pools of normal or anticoagulated plasma (data not shown).

We next performed additional PT assays to test the influence of the tissue thromboplastin preparations and the sequence of reagent addition on the observed reduction in clotting time. To limit experimental variability, these assays were performed

<table>
<thead>
<tr>
<th>Protein concentration (µg/mL)</th>
<th>Normal IgG</th>
<th>No. 1</th>
<th>No. 2</th>
<th>No. 3</th>
<th>No. 4</th>
<th>No. 5</th>
<th>No. 6</th>
</tr>
</thead>
<tbody>
<tr>
<td>dRVVT (seconds prolongation over buffer)</td>
<td>100</td>
<td>46</td>
<td>41</td>
<td>51</td>
<td>30</td>
<td>54</td>
<td>50</td>
</tr>
<tr>
<td>Anti-αβ2-GPI IgG ELISA (OD₄₅₀)</td>
<td>0.035</td>
<td>3.492</td>
<td>3.056</td>
<td>3.026</td>
<td>3.121</td>
<td>2.587</td>
<td>3.320</td>
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</table>
using αβ2-GPI preparations (nos. 1A and 1B) obtained from one of the patients (no. 1).

Table 2 summarizes results of PT performed using 4 additional preparations of tissue thromboplastin (ie, Innovin, Thromborel S, Thromboplastin IS, and IL-HS) and either αβ2-GPI preparation no. 1A (52 µg/mL) or normal IgG (100 µg/mL). The αβ2-GPI IgG antibodies shortened the PT regardless of the thromboplastin preparation used, yielding a mean reduction of 2.1 and 10.1 seconds using normal and anticoagulated plasma, respectively. The reduction in PT was particularly evident in tests performed using anticoagulated plasma and either Thromborel S or Thromboplastin IS (9.8 and 19.3 seconds, respectively).

In the standard PT assay, plasma was preincubated at 37°C for 2 minutes before the addition of calcium-thromboplastin and measurement of clotting time. Results of modified assays in which αβ2-GPI preparation (no. 1B) and thromboplastin were incubated in the absence (−Ca) or presence (+Ca) of calcium ions for 2 minutes before the addition of anticoagulated plasma showed that the sequence of reagent addition did not influence the procoagulating effects of the antibodies with PT reduced by 9.2 seconds in standard assay, and by 7.6 and 10.1 seconds in the −Ca and +Ca assays, respectively.

Results of PT assays performed using a pool of anticoagulated plasma (INR = 3.0) and increasing amounts of a αβ2-GPI preparation no. 1B showed that the reduction in PT was dose-dependent (Fig 3). This IgG preparation shortened PT by 3.2, 6.7, 7.5, 9 seconds when added at a concentration of 5.8, 11.6, 23.2, and 46.5 µg/mL, respectively. The undiluted preparation (93 µg/mL) shortened the PT by 9.2 seconds (ie, from 47.7 seconds using normal IgG to 38.5 seconds).

To ascertain the role of the target antigen, β2-GPI, in αβ2-GPI–mediated PT shortening, PT assays were performed using plasma that had been depleted of β2-GPI by affinity chromatography (see Materials and Methods). Results showed that β2-GPI-depleted plasma exhibited a substantial loss in the ability to shorten PT (ie, from a 9.2-second reduction to a 1.5-second reduction), indicating that the procoagulant effect of αβ2-GPI antibodies is dependent on the presence of their antigen. Moreover, in PT performed by incubating pooled anticoagulated plasma with PL and recombinant-tissue factor (r-TF) for 2 minutes before adding calcium ions, αβ2-GPI IgG did not exhibit procoagulant effect (ie, 45.8 seconds for αβ2-GPI preparation no. 1B vs 47 seconds for normal IgG). Therefore, procoagulant activity of αβ2-GPI IgG is not detectable in PT when plasma is incubated with PL in the absence of calcium ions.

Previous results had shown that the use of diluted tissue...
thromboplastin in TTI yielded comparable PTs in the presence or absence of α2-GPI IgG with LA activity. This prompted us to test whether diluting thromboplastin would affect the procoagulant activity of α2-GPI IgG. As shown in Fig 4, dilution of Recombiplastin progressively abolished the α2-GPI–mediated reduction in PT of both normal and anticoagulated plasma. Therefore, the observed procoagulant effect also depend on the PL/r-TF concentration.

As both dRVVT and PT depend on PL, we reasoned that the distinct abilities of these tests to disclose LA might be influenced by the sequence in which the reagents are mixed. One major difference between the PT and dRVVT protocols is that calcium ions are added together with PL in the former, while they are added after PL in the latter. In fact, modification of the dRVVT protocol by concomitant addition of calcium ions and anionic PL (as in PT) resulted in normal clotting times (Fig 5). The same effect was observed when dRVVT was performed by incubating all reagents for 30 seconds before adding normal pooled plasma. In fact, while affinity-purified α2-GPI antibody preparation no. 1B prolonged conventional dRVVT by 10.3 seconds, it showed no prolongation when normal pooled plasma was added last. The same behavior, ie, no prolongation, was observed when preparation no. 1B was used and calcium ions and normal pooled plasma were added after 30 seconds of incubation of the other reagents. Moreover, an increase in final concentration of calcium from 3 mmol/L to 7 mmol/L completely abolished the LA activity of α2-GPI antibodies (data not shown). These observations showed that detection of α2-GPI LA in dRVVT assay requires the incubation of plasma with PL in the absence of calcium ions.

Finally, we tested whether this procoagulant effect could be mediated by monocytes, cells known to express tissue factor activity on their surface when provided with specific stimuli. As shown in Table 3, compared with nonactivated monocytes, activated monocytes shortened the clotting time of normal plasma from 220 to 42.6 seconds in the presence of Tris buffer and from 217 to 43.3 seconds in the presence of normal IgG; α2-GPI IgG preparations nos. 4 and 6 exhibited a modest procoagulant effect (ie, reduction in clotting time by 3 seconds and 2.4 seconds, respectively) in the presence of activated monocytes.

DISCUSSION

LA is a strong risk factor for thrombosis, and its association with either arterial or venous thrombosis defines the APS syndrome. Most patients with this condition are treated with oral anticoagulants and undergo PT-INR monitoring, the internationally accepted method used to assess oral anticoagulant treatment. It has been reported that the prolongation of PT in patients with LA reflects both the effect of warfarin and the ‘in vitro’ anticoagulant effect of their autoantibodies; therefore, PT-INR values might not accurately reflect the true level of anticoagulation. The present study was undertaken to elucidate the effect of αβ2-GPI LA, a common LA in patients with APS syndrome, on PT. Results showed that, instead of prolonging PT, these LA accelerate coagulation of both normal plasma and plasma from patients on oral anticoagulant treat-

Table 3. PT of Normal Plasma in the Presence of αβ2-GPI Antibody Preparations Measured Using Monocytes as a Source of Tissue Factor

<table>
<thead>
<tr>
<th>Antibody Preparation</th>
<th>PT (s)</th>
</tr>
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<tbody>
<tr>
<td>Buffer + nonactivated monocytes</td>
<td>220</td>
</tr>
<tr>
<td>Normal IgG + nonactivated monocytes</td>
<td>217</td>
</tr>
<tr>
<td>Buffer + activated monocytes</td>
<td>42.6</td>
</tr>
<tr>
<td>Normal IgG + activated monocytes</td>
<td>43.2</td>
</tr>
<tr>
<td>αβ2-GPI IgG no. 1</td>
<td>43.3</td>
</tr>
<tr>
<td>αβ2-GPI IgG no. 2</td>
<td>42</td>
</tr>
<tr>
<td>αβ2-GPI IgG no. 3</td>
<td>42.6</td>
</tr>
<tr>
<td>αβ2-GPI IgG no. 4</td>
<td>40.2</td>
</tr>
<tr>
<td>αβ2-GPI IgG no. 5</td>
<td>42.6</td>
</tr>
<tr>
<td>αβ2-GPI IgG no. 6</td>
<td>40.8</td>
</tr>
</tbody>
</table>
ment. This explains the observation that (1) PT is seldom influenced in the presence of LA; (2) PT with Simplastin is not affected by monoclonal antibodies against β2-GPI25; and (3) the TTI is not influenced by αβ2-GPI LA.24

The mechanism by which αβ2-GPI antibodies shorten PT (with possible implications between this phenomenon and the occurrence of thromboembolic events) is difficult to explain. Our data show that αβ2-GPI-mediated PT shortening exhibits the following characteristics: (1) it is dose-dependent; (2) it requires the presence of the plasma antigen, β2-GPI; (3) it is not dependent on the type of thromboplastin; (4) it disappears upon dilution of TF and the template PL through which these antibodies recognize their antigen11,24; and (5) it is abolished when calcium ions are added last to initiate clotting. Therefore, αβ2-GPI, β2-GPI, and PL in the presence of calcium ions accelerate thrombin formation when the activator of coagulation is TF.

Some investigators suggest that αβ2-GPI antibodies determine a PL-dependent reduction in the activity of tissue factor pathway inhibitor (TFPI).29 Given that extrinsic factor Xa is more efficiently generated when β2-GPI, TFPI, and anionic PL are all present,29 the accumulated findings led to the hypothesis that an αβ2GPI–β2GPI complexes formed in the presence of anionic PL might inhibit TFPI by impeding the building of the quaternary complex (TFPI/FXa/FVIIa/TF). Our data focus attention on the tissue factor pathway of coagulation to explain the paradox that ‘in vitro’ anticoagulant antibodies have an ‘in vivo’ procoagulant effect.

The ‘in vitro’ anticoagulant effect of αβ2-GPI antibodies is in agreement with the observation that binding of αβ2-GPI/β2-GPI complexes to PL membranes severely impairs the absorption or hinders the lateral mobility and activation of clotting factors.12,30 It was recently shown that increasing ionic strength and calcium ions markedly inhibit the binding of β2-GPI to anionic PL in comparison with coagulation proteins30 and that β2-GPI/αβ2GPI complex formation on the PL surface (planar membrane, PS/PC 20/80) is reduced in the presence of physiological concentrations of calcium ions.11 In the same way, the present study showed that the LA of αβ2-GPI IgG was no longer evident when the dRVVT was modified by adding PL in the presence of calcium ions or in any situation in which β2-GPI (ie, plasma), PL and αβ2-GPI antibodies were allowed to interact in the presence of calcium ions.

It was recently reported that aPL antibodies that induce APS are able to stimulate mononuclear cells to produce a procoagulant activity (PCA) that resembles tissue factor (TF).35 Interestingly, upregulation of the TF pathway with elevated circulating levels of TF and TFPI was demonstrated in patients with APS, thus implicating the TF pathway in the pathogenesis of aPL-related thrombosis.33 Our observation that TF is able to induce a procoagulant effect in normal plasma in the presence of αβ2-GPI might be relevant in relation of the increased circulating levels of TF shown in these patients. On the contrary, TF produced by stimulated normal monocytes did not produce a substantial procoagulant effect, with only 2 of 6 αβ2-GPI IgG preparations producing a mild reduction in PT in comparison to normal IgG.

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