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(71) Applicant: **AMERICAN DIAGNOSTICA INC.**
[US/US]; 500 West Avenue, P.O. Box 110215, Stamford,
CT 06911-0215 (US).

(72) Inventors: **GREENFIELD, Robert, S.**; 27 Johnson
Street, Trumbull, CT 06611 (US). **GUINTO, Enriqueta**;
20 Brookside Drive, Apt. 4-G, Greenwich, CT 06830
(US). **RANZURMAL, Safi**; 193 Clark Street, Milford, CT
06460 (US). **GRAFOS, Nicholas**; 840 Fairfield Woods
Road, Fairfield, CT 06825 (US).

(74) Agents: **HAUG, Edgar, H.** et al.; Frommer Lawrence &
Haug LLP, 745 Fifth Avenue, New York, NY 10151 (US).

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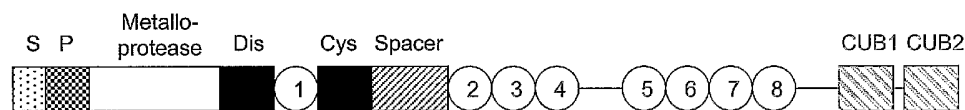
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(54) Title: METHODS AND KITS FOR MEASURING ADAMTS13/FXI COMPLEXES



(57) Abstract: Provided are assays and kits to detect ADAMTS13 activity using peptide substrates and ADAMTS13/Factor XI complexes using ELISA. These assays and kits can be used for diagnostic applications and to evaluate treatment of thrombotic thrombocytopenic purpura (TTP). Also provided is a novel form of ADAMTS13 found on platelets.

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TITLE OF THE INVENTION

Methods and kits for measuring ADAMTS13/FXI complexes

CROSS-REFERENCE TO RELATED APPLICATIONS

- 5 This application is a continuation-in-part of U.S. Patent Application Serial No. 10/894,702, filed July 19, 2004. This application makes reference to International Application No. PCT/US2004/023177, also filed July 19, 2004.

10 This application and each of the documents cited in this application ("application cited documents"), and each document referenced or cited in the application cited documents, either in the text or during the prosecution of this application, as well as all arguments in support of patentability advanced during such prosecution, are hereby incorporated herein by reference. Various documents are also cited in this text ("application cited documents"). Each of the application cited documents, and each document cited or referenced in the
15 application cited documents, is hereby incorporated herein by reference.

FIELD OF THE INVENTION

The invention provides assays for measurement of ADAMTS13 activity and diagnosis of thrombotic thrombocytopenia purpura.

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BACKGROUND OF THE INVENTION

Thrombotic Thrombocytopenia Purpura (TTP) is a life threatening thrombotic microangiopathic disease characterized by hemolytic anemia and thrombocytopenia associated with platelet aggregation. The cause of TTP has been recently linked to
25 abnormalities in a metalloproteinase called ADAMTS13 or von Willebrand factor cleaving protease. ADAMTS13 is an enzyme that is present in significant levels in plasma, and may be expressed in other tissues (Levy *et al.* 2001, Nature 413:488-494; Plaimauer *et al.* 2002, Blood 100:3626-3632). Suzuki *et al.* (2004, Biochem. Biophys. Res. Com. 313:212-216) recently reported ADAMTS13 in platelets.

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ADAMTS13 functions by cleaving ultralarge von Willebrand factor (VWF) multimers to smaller VWF proteins. Decreased VWF cleaving protease activity leads to persistence of unusually large multimers of VWF that bind to platelets, causing platelet aggregates,

microangiopathic hemolysis, and thrombocytopenia in patients with TTP. Clinical manifestations of TTP are difficult to distinguish from hemolytic uremic syndrome (HUS), another thrombotic microangiopathic disorder. Recent studies indicate that low levels of ADAMTS13 activity are associated with TTP, but not HUS (Veyradier A, *et al.* 2002, Blood 98:1765-1772; Furlan *et al.* 1998, Blood 91:2839-2846). Thus, differential diagnosis of TTP can be made by measuring ADAMTS13 activity.

There are two forms of TTP – congenital (familial) and acquired (Furlan *et al.* 1996, Blood 87:4223-4234; Furlan *et al.* 1998, Blood 91:2839-2846). Congenital TTP is caused by genetic mutations in the ADAMTS13 gene, which result in a loss in ADAMTS13 production and/or the production of a non-functional ADAMTS13 enzyme. Acquired TTP is an autoimmune-like disease, which has been linked to intake of certain pharmaceutical drugs. Acquired TTP is caused by the generation of autoantibodies to ADAMTS13 protein. The onset of acquired TTP has been linked to intake of certain pharmaceutical drugs.

Several methods for measuring the presence and/or activity of ADAMTS13 are known in the art. These methods include collagen binding assays, ristocetin cofactor assays, electrophoretic analysis (*e.g.* multimer analysis) and immunological methods. Electrophoretic immunoassays, such as Western blotting analysis, have largely been replaced by immunoradiometric assays (IRMA) and enzyme-linked immunosorbant assays (ELISA) (Laffan *et al.* 2004, Haemophilia 10:199-217). Several reports describe ADAMTS13 assays where the A2 domain of VWF is used as a substrate (Zhou *et al.* 2004, Thromb. Haemost. 91:806-811; Kokame *et al.* 2004, Hemost. Thromb. Vasc. Biol. Blood 103:607-612; Cruz *et al.* 2004, Thromb. Haemost. 90:1204-1209). Cleavage of the A2 domain is monitored by an ELISA method. The available assays for ADAMTS13 require a relatively high technical skill level, and are therefore not performed in most clinical laboratories. In addition, obtaining results can take several days using available tests, which is detrimental to patients presenting with TTP, who require rapid diagnosis.

A simple, specific and rapid assay for ADAMTS13 is needed to solve the problems with the currently available assays; yet one has not been developed to date. Attempts at developing such an assay using ADAMTS13 isolated from plasma have not been successful. Furlan *et al.* tested 28 synthetic chromogenic peptidyl substrates with para-nitroaniline (pNA) as the

leaving group, and did not observe consistent, repeatable results (2002 Seminars in Thrombosis and Hemostasis 28(2): 167-172). These results demonstrate the difficulty in the art of developing a rapid, reliable assay for ADAMTS13 activity.

5 We have discovered that ADAMTS13 on platelets has an enhanced ability, relative to ADAMTS13 in plasma, to cleave small peptidyl substrates. The difference between plasma and platelet ADAMTS13 is likely due to the finding that platelet ADAMTS13 is cleaved, while plasma ADAMTS13 is not cleaved and remains a single polypeptide. The ADAMTS13 activity on platelets can be enhanced by treatment with activated coagulation
10 Factor XI (FXIa). This indicates that FXIa may cause cleavage of ADAMTS13. We have developed diagnostic chromogenic assays for measuring ADAMTS13 activity on platelets and in plasma using different peptidyl substrates with leaving groups other than pNA. We have also developed an assay method to measure autoantibodies to ADAMTS13 and an ELISA for measuring ADAMTS13 protein in plasma. In addition, we have developed an
15 ELISA for measuring ADAMTS13/FXI complexes in plasma.

SUMMARY OF THE INVENTION

In one aspect, the invention provides a method for measuring ADAMTS13 activity comprising (a) incubating a sample comprising ADAMTS13 with a substrate, wherein the
20 substrate comprises a peptide moiety and a chromogenic or fluorogenic moiety, wherein the peptide moiety comprises X-Val-Tyr, X-Leu-Tyr or X-Ile-Tyr, wherein X is any amino acid, and wherein the chromogenic moiety is not para-nitroanaline (pNA); and (b) measuring optical density or fluorescence of the sample; thereby measuring ADAMTS13 activity.

25 In a second aspect the invention provides a method for measuring ADAMTS13 activity comprising (a) incubating a sample comprising ADAMTS13 with a substrate, wherein the substrate comprises X-peptide moiety-Z, wherein the peptide moiety comprises Val-Tyr-Met, Leu-Tyr-Met or Ile-Tyr-Met, wherein X is a donor moiety and Z is an acceptor moiety,
30 and wherein the donor and acceptor moieties mediate fluorescence resonance energy transfer; and (b) measuring fluorescence of the sample; thereby measuring ADAMTS13 activity.

Also provided by the invention is an ADAMTS13 protein isolated from platelets, wherein the ADAMTS13 protein is cleaved into more than one peptide, and wherein at least one cleaved peptide has a molecular weight on an SDS-PAGE gel of about 120 kD or less than 120 kD.

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The invention also provides a method for making an ADAMTS13 substrate for measuring ADAMTS13 activity comprising covalently linking a peptide moiety to a chromogenic or fluorogenic moiety, wherein the peptide moiety comprises X-Val-Tyr, X-Leu-Tyr or X-Ile-Tyr, wherein X is any amino acid, and wherein the chromogenic moiety is not pNA.

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In a fifth aspect, the invention provides a method for making an ADAMTS13 substrate for measuring ADAMTS13 activity comprising covalently linking a donor moiety, a peptide moiety and an acceptor moiety sequentially, wherein the peptide moiety comprises Val-Tyr-Met, Leu-Tyr-Met or Ile-Tyr-Met, and wherein the donor and acceptor moieties mediate

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fluorescence resonance energy transfer.

Another embodiment of the invention is a kit comprising a substrate for measuring ADAMTS13 activity, wherein the substrate comprises a peptide moiety as described herein and a chromogenic or fluorogenic moiety. Alternatively, the substrate comprises donor

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moiety, a peptide moiety as described herein, and an acceptor moiety, wherein the donor and acceptor moieties mediate fluorescence resonance energy transfer.

In another aspect, the invention provides a method for inhibiting ADAMTS13 activity comprising incubating a sample comprising ADAMTS13 with an inhibitory antibody

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against ADAMTS13.

In a further aspect, the invention provides a method for identifying an inhibitor of ADAMTS13 comprising (a) incubating a sample comprising ADAMTS13 with a candidate inhibitor of ADAMTS13; and measuring ADAMTS13 activity in the test sample according

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to the method of the first or second aspect of the invention; wherein the inhibitor is identified by reduced ADAMTS13 activity in the sample compared with ADAMTS13 activity in a control sample comprising ADAMTS13, wherein the control sample was not incubated with the candidate inhibitor.

The invention additionally provides a method for measuring the amount of ADAMTS13 in a sample comprising (a) binding anti-ADAMTS13 antibody to a solid phase; (b) adding the sample to the solid phase, wherein ADAMTS13 present in the sample binds to the antibody;
5 (c) detecting bound ADAMTS13 using direct or indirect immunolabelling; and (d) quantifying ADAMTS13 detected; thereby measuring the amount of ADAMTS13 in the sample.

Another method provided by the invention is a method for detecting anti-ADAMTS13
10 antibodies in a test sample comprising (a) binding an anti-ADAMTS13 antibody raised in a first species to a solid phase; (b) adding ADAMTS13 to the solid phase, wherein the ADAMTS13 binds to the antibody raised in the first species; (c) adding the test sample to the solid phase, wherein the sample is from a second species and wherein anti-ADAMTS13
15 antibodies present in the test sample bind to the ADAMTS13; (d) adding a labeled antibody against antibodies from the second species, wherein the labeled antibody is raised in a third species, wherein the labeled antibody binds to the anti-ADAMTS13 antibodies bound to the ADAMTS13; and (e) detecting the labeled antibody; thereby detecting anti-ADAMTS13 antibodies in the test sample.

20 In another aspect, the invention provides a method for diagnosing TTP in a subject comprising (a) measuring ADAMTS13 activity in a test sample from the subject according to the method of the first or second aspect of the invention; and (b) comparing the ADAMTS13 activity in the test sample to ADAMTS13 activity in a control sample having normal ADAMTS13 activity; wherein TTP is diagnosed by reduced ADAMTS13 activity in
25 the test sample compared with the control sample.

In yet another aspect, the invention provides a method for diagnosing acquired TTP in a subject comprising (a) incubating a sample comprising ADAMTS13 with plasma from the subject; and (b) measuring ADAMTS13 activity in the sample according to the method of
30 the first or second aspect of the invention; wherein acquired TTP is diagnosed by reduced ADAMTS13 activity in the sample compared with ADAMTS13 activity in a control sample having normal ADAMTS13 activity.

The invention additionally provides a method for monitoring treatment of a patient with TTP comprising measuring ADAMTS13 activity according to the first or second aspect of the invention during treatment of the patient.

- 5 A further aspect of the invention provides a method for detecting ADAMTS13/FXI complexes in a sample, comprising (a) binding an anti-ADAMTS13 antibody to a solid phase; (b) adding the sample to the solid phase, wherein the ADAMTS13/FXI complexes present in the sample bind to the antibody; (c) adding an anti-FXI antibody to the solid phase; and (d) detecting the ADAMTS13/FXI complexes by direct or indirect
10 immunolabelling of the anti-FXI antibody.

In another aspect, the invention provides a method for measuring the amount of ADAMTS13/FXI complexes in a sample, comprising (a) binding an anti-ADAMTS13 antibody to a solid phase; (b) adding the sample to the solid phase, wherein the
15 ADAMTS13/FXI complexes present in the sample bind to the antibody; (c) adding an anti-FXI antibody to the solid phase; (d) detecting the ADAMTS13/FXI complexes by direct or indirect immunolabelling of the anti-FXI antibody; and (e) quantifying the anti-FXI antibody detected, thereby measuring the amount of ADAMTS13/FXI complexes in the sample.

20 An additional embodiment of the invention is a method for diagnosing TTP in a subject comprising (a) measuring the amount of ADAMTS13/FXI complexes in a test sample by binding an anti-ADAMTS13 antibody to a solid phase; (b) adding the test sample to the solid phase, wherein the ADAMTS13/FXI complexes present in the test sample bind to the
25 antibody; (c) adding an anti-FXI antibody to the solid phase; (d) detecting the ADAMTS13/FXI complexes by direct or indirect immunolabelling of the anti-FXI antibody; (e) quantifying the anti-FXI antibody detected, thereby measuring the amount of ADAMTS13/FXI complexes in the sample; and (f) comparing the amount of
30 ADAMTS13/FXI complexes in the test sample to the amount of ADAMTS13/FXI complexes in a control sample having normal ADAMTS13 activity. TTP is diagnosed by a reduced amount of ADAMTS13/FXI complexes in the test sample compared with the control sample.

Also provided is a kit for detecting ADAMTS13/FXI complexes in a sample. The kit of the invention comprises (i) a solid phase coated with an anti-ADAMTS13 antibody and (ii) an anti-FXI antibody. In a preferred embodiment, the anti-FXI antibody is labeled. In a particularly preferred embodiment, the anti-FXI antibody is conjugated to horseradish peroxidase (HRP). Optionally, the kit can include an HRP substrate. The kit can also contain a sample for devising a standard curve of ADAMTS13/FXI complex concentration. The standard sample can be any of the samples described herein, including biological fluid, whole blood, platelet rich plasma (PRP), platelet poor plasma (PPP), pooled normal plasma (PNP), washed platelets, tissue culture supernatant and recombinant proteins. The standard sample can be serially diluted by the end user to obtain a standard curve. Other optional components of the kit include a wash buffer, and a positive control. The positive control can also be any of the samples described herein.

In an especially preferred embodiment, the kit of the invention comprises (i) a plate coated with an anti-ADAMTS13 antibody; (ii) an anti-FXI antibody labeled with HRP; (iii) an HRP substrate; (iv) a standard sample; (v) a positive control; and (vi) a wash buffer.

In a further aspect, the invention provides a method of regulating the activity of ADAMTS13 and/or FXI and/or FXIa by enhancing or inhibiting formation of ADAMTS13/FXI complexes.

Another embodiment of the invention is a method of treating TTP or other blood-related diseases by administering to a patient in need thereof, a therapeutically-effective amount of ADAMTS13/FXI complexes.

BRIEF DESCRIPTION OF THE DRAWINGS

The present invention will now be described by way of example, in which reference will be made to the following Figures in which:

Figure 1 shows the structure of the plasma form of ADAMTS13. S: signal peptide; P: propeptide; Dis: disintegrin-like region; Cys: Cys-rich region. The catalytic (metalloprotease) region and the two CUB domains are also shown. Thrombospondin type I (TSP1) repeats are shown as numbered circles.

Figure 2 shows LVY-pNA as a substrate for ADAMTS13.

Figures 3 shows a comparison of LVY-AMC and Suc-LLVY-AMC substrates for measuring ADAMTS13 activity.

Figure 4 shows the measurement of cleavage of an ADAMTS13 substrate using fluorescence resonance energy transfer (FRET). The substrate, NH₂-Arg-Lys(*DABCYL*)-NLVYMVTGD(*EDANS*)-Arg-COOH, was incubated with normal platelets, and the increase in fluorescence over time was measured.

Figure 5 shows ADAMTS13 activity in tissue culture fluid from mock transfected and ADAMTS13 transfected HEK 293 cells. Activity was measured using Suc-LLVY-AMC fluorescent substrate.

Figure 6 shows a comparison of ADAMTS13 activity in plasma from normal subjects and from subjects with acquired TTP using Suc-LLVY-AMC fluorescent substrate.

Figure 7 shows the quantitation of ADAMTS13 activity in PRP from normal subjects (■) and subjects with acquired TTP (◆).

Figure 8 shows the measurement of ADAMTS13 activity in platelet rich plasma (PRP) and platelet poor plasma (PPP) from six individual samples taken from normal subjects. ADAMTS13 activity was measured using Suc-LLVY-AMC fluorescent substrate.

Figure 9 shows a comparison of ADAMTS13 activity per mg of protein on platelets from normal subjects and subjects with acquired TTP.

Figure 10 shows immunostaining Western blots of platelet proteins by various anti-ADAMTS13 antibodies. Figure 10A shows platelet proteins electrophoresed using reducing conditions (lanes A and B) and non-reducing conditions (lanes C and D). Lanes A and C were stained with goat anti-PAI-1 antibody as a control; Lanes B and D were stained with goat anti-ADAMTS13 antibody; Lane E contains molecular weight standards. Arrows on the left indicate protein bands specifically immunostained by anti-ADAMTS13 antibodies. Figure 10B shows immunostaining of platelet proteins using human antibodies. Lane A: reducing conditions and Ig from a subject with acquired TTP; Lane B: non-reducing conditions and Ig from a subject with acquired TTP; Lane C: non-reducing conditions and Ig from a normal subject (control); Lane D: molecular weight markers.

Figure 11 shows that ADAMTS13 activity on normal platelets and on platelets from a subject with acquired TTP is enhanced by treatment with the peptidase activated Factor XIa (FXIa).

Figure 12 shows a plot of FXIa activated platelet ADAMTS13 activity in normal plasma, and its inhibition by plasma from a subject with acquired TTP.

Figure 13 shows a standard curve depicting concentration dependent increase in optical density using the ADAMTS13 ELISA and different amounts of normal plasma.

- 5 Figure 14 shows the determination of ADAMTS13 levels, relative to pooled normal plasma (PNP), in twenty-four individual plasma samples from normal subjects using the ELISA method.

Figure 15 shows inhibition of recombinant ADAMTS13 activity by goat anti-ADAMTS13 antibody.

- 10 Figure 16 shows recombinant ADAMTS13 activity in the presence of varying amounts of normal plasma or plasma from subjects with acquired TTP, which contains an inhibitor of the enzyme.

Figure 17 shows inhibition of ADAMTS13 activity on isolated platelets by anti-ADAMTS13 antibodies from different species.

- 15 Figure 18 shows the results of an experiment measuring anti-ADAMTS13 autoantibodies in plasma by preincubating sample plasma with isolated normal platelets.

Figure 19 shows concentration dependent inhibition of platelet ADAMTS13 activity by human ADAMTS13 antibodies in plasma from subjects with acquired TTP.

- 20 Figure 20 shows the effect of using different amounts of platelets in the fluorescence assay of the invention. ADAMTS13 activity was measured in PRP from normal subjects and subjects with acquired TTP.

Figure 21 shows a standard curve using an ELISA of the invention to measure the level ADAMTS13/FXI complexes in various concentrations of normal plasma.

- 25 Figure 22 shows complex formation between recombinant ADAMTS13 and FXI immobilized on a microtiter plate.

Figure 23 shows the level of ADAMTS13/FXI complexes in FXI-deficient plasma, compared with normal plasma.

Figure 24 shows that increasing amounts of ADAMTS13/FXI complexes were formed in FXI-deficient plasma upon addition of increasing amounts of FXI.

DETAILED DESCRIPTION

In this disclosure, "comprises", "comprising", "containing", "having" and the like can have the meaning ascribed to them in U.S. Patent law and can mean "includes", "including", and the like. "Consisting essentially of" or "consists essentially of" likewise have the meaning
5 ascribed in U.S. Patent law and the term is open-ended, allowing for the presence of more than that which is recited so long as basic or novel characteristics of that which is recited is not changed by the presence of more than that which is recited, but excludes prior art embodiments.

10 ADAMTS13

ADAMTS13, also known as von Willebrand factor (VWF)-cleaving protease, is a member of the family of metalloproteases named for the characteristic combination of a disintegrin-like and metalloprotease (reprolysin-type), with thrombospondin type 1 motifs. The structure of plasma ADAMTS13 is shown in Figure 1. Structural details and sequence
15 information on ADAMTS13 can be found in Zheng *et al.* (2001; J. Biol. Chem. 276(44):41059-41063). ADAMTS13 cleaves VWF at the Tyr¹⁶⁰⁵—Met¹⁶⁰⁶ bond and requires both calcium and zinc ions to function.

Until the instant invention, ADAMTS13 activity was primarily studied in plasma. This
20 form of ADAMTS13 is referred to herein as "plasma ADAMTS13". A novel form of ADAMTS13 has now been discovered on platelets and is referred to herein as "platelet ADAMTS13". "Recombinant ADAMTS13" can also be made using standard molecular biology techniques, such as those found in Sambrook, *et al.*, Molecular Cloning, A Laboratory Manual (1989) and Ausubel *et al.*, Short Protocols in Molecular Biology (1999)
25 4th Ed., John Wiley & Sons, Inc. (as well as the complete version of Current Protocols in Molecular Biology).

Therefore, the invention provides an ADAMTS13 protein and ADAMTS13 activity in platelets. This protein appears to be distinct from plasma ADAMTS13 in that plasma
30 ADAMTS13 is one contiguous polypeptide, whereas platelet ADAMTS13 protein is cleaved into more than one polypeptide, which is then held together by disulfide bonds. Polypeptides of about 120 kD, about 84 kD, about 60 kD, about 43 kD and about 30 kD are seen on an SDS-PAGE gel of platelet ADAMTS13. Platelet ADAMTS13 appears to be

cleaved by FXIa. Likewise, this form of ADAMTS13 also appears to be distinct from that reported by Suzuki *et al.* (2004, Biochem. Biophys. Res. Commun. 313:212-216). Unlike the cleaved platelet ADAMTS13 of the instant invention, the ADAMTS13 of Suzuki *et al.* has a molecular weight of about 220 kD on an SDS-PAGE gel. Moreover, Suzuki *et al.*

5 report the larger form of ADAMTS13 in platelets, while experiments performed by the current inventors indicate ADAMTS13 activity on the surface of platelets. Without wishing to be bound by theory, it is possible that the platelet ADAMTS13 of the invention has undergone different post-translational modification than that of Suzuki *et al.*, resulting in a cleaved surface protein, rather than a larger cytoplasmic protein.

10 The assays of the invention can be used to detect platelet ADAMTS13, plasma ADAMTS13 and recombinant ADAMTS13.

Sources of ADAMTS13 for use in the assays and methods of the invention can be platelet
15 rich plasma (PRP), platelet poor plasma (PPP), pooled normal plasma (PNP), isolated platelets, whole blood, tissue culture supernatant or purified ADAMTS13. Methods for making PRP, PPP, isolated platelets and tissue culture supernatant can be found in the Examples section. Purified ADAMTS13 can be made from plasma, platelets or recombinant cells using standard biochemical techniques for protein isolation and
20 purification including, but not limited to, immunoaffinity chromatography, size exclusion chromatography, ion exchange chromatography, immunoprecipitation, and ammonium sulfate precipitation. The term "plasma" can include PRP, PPP and PNP.

As used herein, "normal platelets", "normal plasma", "normal PRP", *etc.* are derived from
25 individuals who do not have either congenital TTP or acquired TTP. PNP is a mixture of plasma taken from multiple individuals who do not have TTP. Likewise, "TTP platelets", "TTP plasma", "TTP PRP", *etc.* are derived from individuals who have either congenital TTP or acquired TTP. "Acquired TTP platelets", "acquired TTP plasma", "acquired TTP PRP", *etc.* are derived from individuals who have the acquired form of TTP.

30 Measurements of ADAMTS13 activity are made in relation to "normal activity", that is, ADAMTS13 activity in normal platelets, normal plasma, normal PRP, recombinant or purified ADAMTS13 *etc.* Thus, terms such as "reduced ADAMTS13 activity" or

“inhibited ADAMTS13 activity” refer to ADAMTS13 activity relative to activity measured in a normal sample, *i.e.* normal platelets, normal plasma, normal PRP, recombinant or purified ADAMTS13 *etc.*

- 5 The methods of the invention are applicable to clinical, veterinary and/or research applications.

Factor XI

Factor XI (FXI) is a zymogen of the plasma serine protease family that, upon activation,
10 participates in both fibrin formation and fibrinolysis (von dem Borne *et al.* 1995, Blood 86:3035-3042). FXI is comprised of 2 identical 80-kD polypeptides connected by a single disulfide bond. The protein has an N-terminal non-catalytic heavy chain and a C-terminal trypsin-like catalytic light chain. The heavy chain consists of 4 homologous subunits called “apple” domains, a feature that FXI shares with the closely related prekallikrein (Gailani *et*
15 *al.* 2001, Blood 17:3117-3122).

FXI is activated *in vitro* by activated Factor XII (FXIIa), thrombin, and activated Factor XI (FXIa) (Gailani. *et al.* 1991, Science 253:909). Evidence strongly suggests that FXI and FXIa bind to activated platelets in a manner that requires the protein cofactor high
20 molecular weight kininogen, and zinc ions (Sinha *et al.* 1984, J. Clin. Invest. 73:1550-1559). FXI and FXIa both bind to activated platelets (Greengard, J. et al (1986) Biochemistry 25: 3884-3890).

The present inventors have found that both FXI and FXIa bind to ADAMTS13. A complex
25 is thereby formed between ADAMTS13 and FXI or FXIa. The invention comprehends both ADAMTS13-FXI complexes and ADAMTS13-FXIa complexes. FXIa appears to cleave ADAMTS13. Without wishing to be bound by theory, it is believed that cleavage of ADAMTS13 by FXIa increases the activity of ADAMTS13. The invention provides methods of detecting ADAMTS13-FXI complexes in a sample. Detection of complexes can
30 be used as a measure of ADAMTS13 levels and/or activity, and can be diagnostic for TTP and other hemostatic conditions.

Sources of FXI for use in the assays and methods of the invention can be platelet rich plasma (PRP), platelet poor plasma (PPP), pooled normal plasma (PNP), isolated platelets, whole blood, tissue culture supernatant or purified FXI. Purified FXI can be made from plasma, platelets or recombinant cells using standard biochemical techniques for protein isolation and purification including, but not limited to, immunoaffinity chromatography, size exclusion chromatography, ion exchange chromatography, immunoprecipitation, and ammonium sulfate precipitation. As used herein, "FXI-deficient plasma" is derived from individuals with a congenital or acquired FXI deficiency.

10 Substrates

The invention relates to assays for measuring ADAMTS13 activity. In one such assay, a sample comprising ADAMTS13 is incubated with a substrate that comprises a peptide moiety and a chromogenic or fluorogenic moiety and the optical density or fluorescence of the sample is measured, thereby measuring ADAMTS13 activity. In this embodiment, the peptide moiety comprises X-Val-Tyr, X-Leu-Tyr or X-Ile-Tyr, wherein X is any amino acid. In a preferred embodiment, X is Leu. In other preferred embodiments, the peptide moiety is Leu-Val-Tyr, Leu-Leu-Val-Tyr or Suc-Leu-Leu-Val-Tyr.

The skilled artisan can make amino acid substitutions in the peptide moiety without undue experimentation. For example, amino acid substitutions may be made on the basis of similarity in polarity, charge, solubility, hydrophobicity, hydrophilicity, and/or the amphipathic nature of the residues as long as the binding activity of the substrate is retained. For example, negatively charged amino acids include aspartic acid and glutamic acid; positively charged amino acids include lysine and arginine; and amino acids with uncharged polar head groups having similar hydrophilicity values include leucine, isoleucine, valine, glycine, alanine, asparagine, glutamine, serine, threonine, phenylalanine, and tyrosine.

Conservative substitutions may be made, for example, according to the Table below.

Amino acids in the same block in the second column and preferably in the same line in the third column may be substituted for each other:

ALIPHATIC	Non-polar	G A P
		I L V
	Polar – uncharged	C S T M
		N Q
	Polar – charged	D E
		K R
AROMATIC		H F W Y

Preferably, the peptide moiety is at least about 3 amino acid residues in length. More preferably, the peptide moiety is in the range of about 3 to about 20 amino acid residues in length. Non-conventional amino acids such as those found in the Spectrozyme series of peptidyl substrates from American Diagnostica Inc. (Stamford, CT) may also be used to substitute for conventional amino acids, provided that the peptide retains its ability to bind to and be cleaved by ADAMTS13.

Chromogenic moieties suitable for use in the invention include *s*-benzyl, 5-amino-2-nitrobenzoic acid and 6-amino-1-naphthalenesulfonamides. The chromogenic moiety is not para-nitroaniline (pNA), which has been demonstrated to be an ineffective moiety for an ADAMTS13 substrate. Without wishing to be bound by theory, it is possible that the structure of pNA creates a steric hindrance that prevents ADAMTS13 activity.

Fluorogenic moieties suitable for use in the invention include coumarins, fluoresceins, rhodamines, resorufins and dimethylacridinones. In a preferred embodiment, the fluorogenic moiety is a coumarin. In a particularly preferred embodiment, the coumarin is 7-amino-4-methylcoumarin (AMC).

Another assay provided by the invention is a method for measuring ADAMTS13 activity by incubating a sample comprising ADAMTS13 with a substrate having donor and acceptor moieties that mediate fluorescence resonance energy transfer (FRET). In addition to the donor and acceptor moieties, the substrate comprises a peptide moiety that comprises Val-Tyr-Met, Leu-Tyr-Met or Ile-Tyr-Met. ADAMTS13 activity is determined by measuring the fluorescence of the sample.

FRET is a distance-dependent interaction between the electronic excited states of two dye molecules in which excitation is transferred from a donor moiety to an acceptor moiety without emission of a photon. This is accomplished by using donor/acceptor pairs in which the emission spectrum of the donor overlaps the absorption spectrum of the acceptor. When the two are in spatial proximity, the excitation energy of the donor is transferred to the acceptor through long-range dipole-dipole interactions. When energy transfer occurs, the acceptor quenches the fluorescence of the donor, and thus, the acceptor moiety is also called a quencher. The donor and acceptor moieties must be within about 100 angstroms or 10 nm of one another for efficient energy transfer.

Suitable donor/acceptor pairs for use in FRET are well known in the art. Examples of donor/acceptor pairs can be found in Table 1. It should be noted that Table 1 does not contain an exhaustive list of FRET donor/acceptor pairs, and that the skilled artisan can choose a donor/acceptor pair based on his or her knowledge of the art.

Table 1. FRET Donor and Acceptor Moieties

Donor	Acceptor
7-Methoxycoumarin	DABCYL
Amino Methyl Coumarin	DABCYL, QSY-35 ¹
Blue Fluorescent Protein	Ds Red Fluorescent Protein
BODIPY-FL ²	DABCYL, QSY-7, QSY-9, BHQ-1 ³
B-Phycoerythrin	Cy5
Carboxyfluorescein Succinimidyl Ester	Texas Red
Cascade Blue	DABCYL
Coumarin	DABCYL
Cy3	Cy5, QSY-7, QSY-9, BHQ-2
Cy5	Cy5.5, QSY-35, BHQ-2
Dansyl	FITC
Dansyl	Octadecylrhodamine
Dialkylaminocoumarin	DABCYL, QSY-35
EDANS ⁴	DABCYL
FITC	Eosin Thiosemicarbazide
Fluorescein	Tetramethylrhodamine
Green Fluorescent Protein	Yellow Fluorescent Protein
IAEDANS ⁵	DDPM ⁶
Marina Blue	DABCYL, QSY-35
Pacific Blue	DABCYL, QSY-35
Rhodamine 6G	Malachite Green
Tryptophan	Dansyl

¹ QSY quenchers are analogs of fluorescein.

² 4,4-difluoro-4-bora-3a,4a-diaza-s-indacene

³ Black Hole Quenchers™ by Biosearch Technologies, Inc., Novato, CA

5 ⁴ 5-[(2-aminoethyl)amino]naphthalene-1-sulfonic acid

⁵ 5-(2-iodoacetylaminomethyl)aminonaphthalene-1-sulfonic acid

⁶ N-(4-dimethylamino-3,5-dinitrophenyl)maleimide

The preferred donor/acceptor pair is EDANS/DABCYL.

Preferably, the peptide moiety is at least about 3 amino acid residues in length. More preferably, the peptide moiety is in the range of about 3 to about 30 amino acid residues in length. Advantageously, the peptide moiety is Asn-Leu-Val-Tyr-Met-Val-Thr-Gly-Asp. Amino acid substitutions can be made as described above without departing from the spirit and scope of the invention.

The preferred substrate for use in this embodiment of the invention is NH₂-Arg-Lys-(DABCYL)-Asn-Leu-Val-Tyr-Met-Val-Thr-Gly-Asp-(EDANS)-Arg-COOH.

Methods for making the ADAMTS13 substrates of the invention are also contemplated. Said methods comprise covalently linking a peptide moiety, as described above, to a chromogenic or fluorogenic moiety, or to a donor moiety and an acceptor moiety that mediate FRET, using well known synthesis techniques.

Inhibitors of ADAMTS13

An embodiment of the invention involves a method for inhibiting ADAMTS13 using an inhibitory antibody against ADAMTS13. Several anti-ADAMTS13 antibodies are available from various sources. For instance, Examples 12 and 14 demonstrate the inhibitory effects of anti-ADAMTS13 antibodies from goat, rabbit and human.

Autoantibodies that inhibit ADAMTS13 activity can be detected in subjects with acquired TTP. (See Klaus *et al.* 2004, Blood 103(12):4514-4519.) These antibodies can be isolated from the plasma of acquired TTP patients and used *in vitro* as inhibitors of ADAMTS13. Moreover, a method of diagnosing acquired TTP provided by the instant invention is to incubate an ADAMTS13 sample with plasma from a subject to be tested for acquired TTP and to measure ADAMTS13 activity using one of the assays of the invention. Inhibition of ADAMTS13 activity by the plasma indicates the presence of inhibitory anti-ADAMTS13 antibodies in the plasma, and thus confirms a diagnosis of acquired TTP.

Klaus *et al.* (*Ibid*) performed epitope mapping experiments in order to deduce the nature of inhibitory ADAMTS13 antibodies in patients with acquired TTP. The results indicate that antibodies directed against the cysteine rich/spacer domain of ADAMTS13 were detected in all cases. In addition, antibodies directed against the TSP1-1 repeat or a fragment

containing the TSP1-1 repeat, the disintegrin-like domain and the catalytic domain were detected in 72% of patients. Further, antibodies directed against the CUB 1 and/or CUB 2 domains were detected in 64% of patients. For purposes of this invention, the C-terminus consists of thrombospondin type 1 TSP1 repeats 2-8 and the CUB domains. Figure 1 shows a schematic diagram of ADAMTS13.

The invention provides a method for identifying inhibitors of ADAMTS13. The inhibitor can be, *inter alia*, a polypeptide, a peptide, an oligonucleotide, a polynucleotide, a nucleoside or nucleoside analog, a saccharide, a small molecule, or a natural or synthetic chemical. The method comprises incubating a sample of ADAMTS13 with a candidate inhibitor and measuring ADAMTS13 activity according to one or more of the assays provided by the invention. The inhibitor is identified by reduced ADAMTS13 activity in the test sample, compared with ADAMTS13 activity in a control sample not incubated with the candidate inhibitor. The candidate inhibitor can be generated using known techniques, and can be derived, for example, from a chemical compound library, a phage display library, a natural chemical library or a combinatorial chemistry library.

ELISA

The Enzyme Linked Immunosorbent Assay (ELISA) is a solid-phase immunoassay that is widely used in both clinical and basic research settings. In one type of ELISA, an antigen is attached to the solid phase, which is most commonly a membrane, plate, microwell or bead. The solid phase is then incubated with an antibody to the antigen (a "primary antibody"). If the primary antibody is conjugated to a label, it can be detected. This process is known as direct immunolabelling. Alternatively, the primary antibody may be unlabeled, in which case an antibody to the primary antibody (a "secondary antibody"), raised in a different species from the primary antibody and conjugated to a label, is incubated with the solid phase. This detection method is referred to as indirect immunolabelling. Immunolabelling methods are well known in the art.

In a different type of ELISA, an antibody is attached to the solid phase. This antibody can then be used to capture an antigen of interest. Direct or indirect immunolabelling techniques can be employed for the sake of analysis. In the instant invention, ADAMTS13 in a sample can be measured by binding an anti-ADAMTS13 antibody to a solid phase and

adding the sample to the solid phase. ADAMTS13 present in the sample binds to the antibody, and bound ADAMTS13 is detected using direct or indirect immunolabelling. The amount of ADAMTS13 in the sample can be measured by quantifying the label.

- 5 In a preferred embodiment, the sample is or comprises platelets. In another preferred embodiment, the sample is plasma.

Another ELISA provided by the invention is used to detect anti-ADAMTS13 antibodies in a test sample. In this embodiment, an anti-ADAMTS13 antibody raised in a first species, *e.g.* a goat, is bound to a solid phase. ADAMTS13 is added and binds to the antibody raised in the first species. A test sample from a second species, *e.g.* human, is added, and any anti-ADAMTS13 antibodies present in the test sample bind to the ADAMTS13. Finally, a labeled antibody against antibodies from the second species is added. The labeled antibody is raised in a third species, *e.g.* donkey, and binds to the antibody from the second species.

10 By detecting the label, one can detect anti-ADAMTS13 antibodies in the test sample.

Another ELISA provided by the invention is used to detect ADAMTS13-FXI complexes in a sample. In one embodiment, an anti-ADAMTS13 antibody is bound to a solid phase. A sample is added to the solid phase and the ADAMTS13-FXI complexes present in the sample bind to the antibody. An anti-FXI antibody is added and the ADAMTS13-FXI complex is detected by direct or indirect labeling with a chromogenic or fluorescent moiety, as described herein. The amounts of ADAMTS13-FXI complexes are quantified by detection of the label.

20

25 In another embodiment, FXI is bound to a solid phase and a test sample containing ADAMTS13 is added to the solid phase and forms a complex with the immobilized FXI. An anti-ADAMTS13 antibody is added and binds to the ADAMTS13/FXI complexes. The ADAMTS13 antibody can be detected by direct or indirect labeling as described herein.

30 The test sample can be any biological fluid, such as blood, plasma, serum, culture fluid, cerebrospinal fluid or sputum. In a preferred embodiment, the biological fluid is plasma.

The label can be any moiety known in the art, including chromogenic enzyme systems, such as horseradish peroxidase, alkaline phosphatase, β -galactosidase, glucose 6-phosphate dehydrogenase. These enzyme labels are reacted with a chromogenic substrate that can be detected by conventional techniques. In a preferred embodiment, the label is horse radish peroxidase, and the substrate is tetramethylbenzidine. The label can also be a fluorescent dye, including rhodamine, fluorescein, Cy dyes, Texas Red, and derivatives thereof.

Diagnostic Applications

In addition to the method discussed above for diagnosing acquired TTP by testing the inhibitory properties of plasma on an ADAMTS13 sample, the invention provides other methods for the diagnosis of both congenital and acquired TTP.

For example, congenital or acquired TTP can be diagnosed by measuring ADAMTS13 activity in a test sample from a subject using one of the assays of the invention and subsequently comparing the ADAMTS13 activity in the test sample to ADAMTS13 activity in a control sample having normal ADAMTS13 activity. Reduced ADAMTS13 activity in the test sample compared with the control sample indicates a positive diagnosis of TTP.

Congenital or acquired TTP can also be diagnosed by measuring the amount of ADAMTS13/FXI complexes in a test sample from a subject using the ELISA described herein and subsequently comparing the amount of complexes in the test sample to the amount of complexes in a control sample having normal ADAMTS13 activity. A reduced level of ADAMTS13/FXI complexes in the test sample compared with the control sample indicates a positive diagnosis of TTP. As shown in Example 20, there is a linear correlation between ADAMTS13 activity and the level of ADAMTS13/FXI complexes in a sample.

Acquired TTP can be diagnosed in a subject by incubating a sample comprising ADAMTS13 with plasma from the subject; and measuring ADAMTS13 activity in the sample using one of the assays of the invention. Reduced ADAMTS13 activity in the sample, compared with ADAMTS13 activity in a control sample having normal ADAMTS13 activity, indicates acquired TTP.

Treatment Applications

The techniques provided by the invention can be used to monitor treatment of a patient for TTP. For example, during treatment, ADAMTS13 activity can be measured using the assays of the invention. This allows the clinician to assess the efficacy of the treatment and/or to determine the length of a treatment session that is required to restore ADAMTS13 activity.

One treatment for TTP is plasmaphoresis. In patients with acquired TTP, plasmaphoresis is used to remove the inhibitory anti-ADAMTS13 antibodies from the patient's plasma.

Replacement of the deficient ADAMTS13 is provided by infused plasma. Recent advances in our understanding of the pathological mechanisms of TTP provide a rationale for monitoring plasmaphoresis via measuring the levels of ADAMTS13 activity in the patient undergoing plasmaphoresis.

Because the platelet form of ADAMTS13 reacts with low molecular weight substrates more efficiently than the plasma form, platelet ADAMTS13 is likely to be a better target for drugs designed to treat TTP. Therefore, the invention provides a method for treating TTP in a patient in need thereof comprising administering to the patient a drug that specifically targets platelet ADAMTS13. The drug can be identified using the screening methods provided by the invention and described herein. The term "drug" is meant to encompass a polypeptide, a peptide, an oligonucleotide, a polynucleotide or vector containing a polynucleotide, a nucleoside or nucleoside analog, a saccharide, a small molecule, or a natural or synthetic chemical.

The invention will now be further described by way of the following non-limiting Examples, given by way of illustration.

EXAMPLES

Materials and Methods

Synthetic Peptidyl Substrates

Leu-Val-Tyr-AMC (LVY-AMC) and Suc-Leu-Leu-Val-Tyr-AMC (Suc-LLVY-AMC) were obtained from Bachem Bioscience Inc. (King of Prussia, PA). LVY-AMC was also made by QPR (Montreal, Canada). FRET substrate, NH₂-Arg-Lys(DABCYL)-

NLVYMTGD(EDANS)-Arg-COOH, was made for American Diagnostica Inc. by Molecular Biology Resource Center, University of Oklahoma Health Sciences Center (Oklahoma City, OK).

5 Preparation of Platelet Rich Plasma (PRP), Platelet Poor Plasma (PPP) and Isolated Platelets

Blood was collected by venopuncture into collection tubes containing 0.12 M sodium citrate, an anti-coagulant. The citrated blood was centrifuged at 700 rpm for 10 minutes. The supernatant was removed and saved as the platelet rich plasma (PRP) fraction. The PRP was centrifuged at 10,000 rpm for 20 minutes. The supernatant was removed and saved as the platelet poor plasma (PPP) fraction. The pellet contained the platelets, which were washed by resuspending in 10 mM Tris-HCl pH 8.0 buffer and centrifuging at 10,000 rpm for 10 minutes. The isolated platelets were resuspended in buffer and used in experiments.

15

Recombinant ADAMTS13

HEK 293 cells were transfected with a vector encoding ADAMTS13. Cell culture supernatant from the transfected HEK 293 cells, containing recombinant ADAMTS13, was generously provided by Dr. David Ginsburg (University of Michigan, MI). Mock transfected cell supernatant with no recombinant ADAMTS13 was also provided as a control.

20

Example 1. Measurement of ADAMTS13 Activity in PRP Using LVY-pNA and LVY-AMC Peptidyl Substrates

25 As discussed above, Furlan *et al.* reported that some peptidyl-pNA moieties, such as XLY-pNA and XVY-pNA, were not substrates for ADAMTS13. We prepared LVY-pNA and tested it for its ability to be cleaved by ADAMTS13. The results shown in Figure 2 confirm the findings of Furlan *et al.*, *i.e.*, LVY-pNA was not cleaved by ADAMTS13.

30 Thus, the nature of the leaving group of the peptidyl substrate appears to be important in determining the ability of ADAMTS13 to cleave a chromophor or a fluorophor from the end of a peptidyl substrate.

1.

Example 2. Measurement of ADAMTS13 Activity in PRP Using Peptidyl Substrates of Different Lengths

In order to determine the effect of modifying the length of the peptide sequence conjugated to the AMC fluorochrome, normal PRP (20 μ l) was incubated at 37° C with a final concentration of 0.8 mM Suc-LLVY-AMC or LVY-AMC in 10 mM Tris-HCl pH 8.0 buffer in total volume of 200 μ l. Fluorescence was measured using a microtiter fluorophotometric plate reader (Ex 360 nm/ Em 460 nm). Both peptidyl-AMC substrates were cleaved by ADAMTS13 in PRP, with the Suc-LLVY-AMC giving a higher signal over time as compared to the LVY-AMC substrate (Figure 3).

This example demonstrates that different ADAMTS13 substrates can be made by altering the peptide sequence that is conjugated to the AMC fluorophor.

Example 3. Measurement of ADAMTS13 Activity Using a FRET Substrate

ADAMTS13 activity was measured using a fluorescent substrate attached to a donor moiety and an acceptor moiety that functions by fluorescence resonance energy transfer (FRET). The ADAMTS13 selective substrate, NH₂-Arg-Lys(*DABCYL*)-NLVYMVTGD(*EDANS*)-Arg-COOH, was used in this example. The NLVYMVTGD peptide sequence of this substrate is homologous to the ADAMTS13 cleavage site on VWF. The intact peptidyl substrate has low fluorescence, due to quenching of the *DABCYL*-fluorochrome by the *EDANS*-quencher. Cleavage of the substrate between the tyrosine and methionine of the peptide sequence results in an increase in fluorescence.

Isolated platelets in 10mM Tris-HCl pH 8.0 assay buffer were incubated with a final concentration of 8 μ g/ml of the FRET substrate at 37°C. The fluorescence was measured in a spectrofluorometric plate reader (Ex 360 nm/ Em 440 nm). Figure 4 shows that incubation of platelets with NH₂-Arg-Lys(*DABCYL*)-NLVYMVTGD(*EDANS*)-Arg-COOH results in increased fluorescence over time, indicating that the form of ADAMTS13 found on platelets cleaves this FRET peptide substrate. The skilled artisan can design other FRET substrates for measuring ADAMTS13 activity using his or her own knowledge and the teachings herein.

Example 4. Measurement of Recombinant ADAMTS13 Activity in Tissue Culture Supernatants Using Suc-LLVY-AMC Fluorescent Substrate

Fluorescence signals were compared between tissue culture supernatant from HEK 293 cells transfected with a viral vector coding for recombinant ADAMTS13 ("recADAMTS13") and supernatant from mock transfected HEK 293 cells, as a control. (Culture supernatants were supplied by Dr. David Ginsburg, University of Michigan.) Varying amounts of the two culture supernatants were added to 0.8 mM Suc-Leu-Leu-Val-Tyr-AMC fluorescent substrate in 50 mM Tris-HCl pH 8.0 in a total volume of 100 μ l. Figure 5 shows that a greater fluorescence signal was produced by the supernatant from transfected cells verses supernatant from mock transfected cells. The increased fluorescence signal is due to cleavage of the substrate by recADAMTS13 in supernatant of the vector transfected cell supernatant.

2.

Example 5. Measurement of ADAMTS13 Activity in Plasma

ADAMTS13 activity was measured in plasma using the Suc-LLVY-AMC substrate. Normal plasma (50 μ l) or acquired TTP plasma (50 μ l) was added to substrate in 50 mM Tris-HCl pH 8.0 buffer. The final concentration of the substrate was 0.8 mM; substrate in buffer was used as a background control. The reaction mixture was incubated at 37° C for 4 hours and fluorescence was recorded in a spectrofluorometric plate reader at Ex 360 nm/ Em 440 nm (Figure 6). Higher ADAMTS13 activity was observed in the normal plasma as compared to acquired TTP plasma.

Example 6. Comparison of ADAMTS13 Activity in PRP from Normal and TTP Subjects

3. The ADAMTS13 activity from normal plasma and from acquired TTP plasma were compared in the fluorescence assay described above. Specifically, 20 μ l of normal PRP were serially diluted 1:2 in normal PPP in microtiter wells. Eighty μ l of LVY-AMC (0.2 mM final concentration) in 10 mM Tris-HCl pH 8.0 buffer were added to the PRP. The microtiter plate was placed in a spectrofluorometric microtiter plate reader at 37° C and the fluorescence was monitored at Ex 360 nm/ Em 440 nm for 16 minutes.

4.

5. The results shown in Figure 7 demonstrate that, as the amount of PRP in the assay decreased, there was a decrease in the fluorescence signal. PRP from a patient diagnosed

with acquired TTP was tested in the assay under the same conditions as normal PRP. In this experiment, more plasma from the acquired TTP patient (20-60 μ l) was used in the assay, as compared to normal PRP. No fluorescent signal was generated at the highest amount of PRP from the acquired TTP patient. This shows that ADAMTS13 activity in PRP from an acquired TTP patient has significantly less activity than normal PRP. This method can be used to diagnose deficiency in ADAMTS13 activity.

Example 7. ADAMTS13 Activity Is Associated with Platelets

6. PRP and PPP from six normal volunteers were prepared as described above. Fifty μ l of each plasma sample were added to 130 μ l 50 mM Tris-HCl buffer pH 8.0 and 20 μ l of 8 mM Suc-LLVY-AMC substrate. The reaction mixtures were incubated at 37° C and monitored for 1 hour in a spectrofluorometric plate reader at Ex 360 nm/ Em 440 nm. The six PRP samples exhibited high ADAMTS13 activity, as evidenced by generation of a high fluorescence signal (RFU) over time (Figure 8).

7.

8. The rate of fluorescence generation over time was significantly greater in PRP than in plasma. After pelleting of platelets, the PPP from each subject was also tested, and exhibited very little ADAMTS13 activity. These results show that the majority of ADAMTS13 activity in PRP is present on the platelets and not in the plasma.

Example 8. Reduced ADAMTS13 Activity is Associated with Human Platelets from an Acquired TTP Patient

Isolated platelets from a normal subject and from a patient diagnosed with acquired TTP were prepared as described above. Approximately 600 μ g of protein in 100 μ l of 50 mM Tris-HCl pH 8.0 buffer from the normal and the acquired isolated platelets were placed in wells in a fluorescence microtiter plate. LVY-AMC substrate was added to each tube to a final concentration of 0.2 mM and the reaction mixtures were incubated at 37° C for 1 hour. The fluorescence was monitored at Ex 360 nm/ Em 440 nm. The amount of ADAMTS13 activity per mg of protein associated with normal platelets was significantly greater than that associated with platelets from a patient with acquired TTP (Figure 9).

This method can be used to quantitate ADAMTS13 activity on platelets. Low ADAMTS13 activity would indicate TTP. Both congenital TTP, caused by mutation or alteration of

ADAMTS13, and acquired TTP, caused by presence of ADAMTS13 inhibitory antibodies, can be diagnosed using this method.

Example 9. ADAMTS13 Associated with Platelets is Present in a Cleaved Form

- 5 The molecular form of ADAMTS13 in platelets was investigated by immunostaining of Western blots of platelet proteins (Figure 10). Washed platelets were solubilized in SDS-sample buffer with and without mercaptoethanol. SDS-PAGE electrophoresis was performed using 4-20% acrylamide gel. The resolved proteins were electroblotted onto nylon paper and immunostained with different biotinylated anti-ADAMTS13 antibodies and streptavidin-HRP/TMB. A goat anti-ADAMTS13 antibody specifically immunostained protein bands under reducing conditions at approximately 120 kD, 43 kD and 30 kD. Using non-reducing conditions, a high molecular weight band at approximately 150 kD was specifically immunostained.
- 10
- 15 These findings suggest that ADAMTS13 on platelets is comprised of more than one protein held together by disulfide bonds. ADAMTS13 in plasma has been reported to be comprised of a single protein of molecular weight 150-170 kD. The ADAMTS13 associated with platelets is different than plasma ADAMTS13, and appears to be cleaved. ADAMTS13 from platelets was immunostained using plasma from an acquired TTP patient. A high molecular weight band was specifically immunostained under non-reducing conditions. Reduction of the protein caused the ADAMTS13 not to be stained by this TTP plasma.
- 20

Example 10. Enhanced Activity of Platelet ADAMTS13 by Treatment with a Proteolytic Enzyme

- 25 ADAMTS13 on platelets appears to be proteolytically cleaved into at least two or more polypeptide chains held together by disulfide bonds, whereas plasma ADAMTS13 is a single peptide chain. We tested whether a peptidase can cleave ADAMTS13 and increase activity toward ADAMTS13 peptide substrates.
- 30 Figure 11 shows that ADAMTS13 activity on platelets is enhanced by treatment with peptidase activated FXIa. Washed normal platelets from 200 μ L of PRP were resuspended in 1 ml of assay buffer. Washed platelets from 1 ml of PRP from a subject with acquired TTP were resuspended in 50 μ L of assay buffer. Normal or TTP platelets (10 μ L) were

added to 10 mM Tris-HCl pH 8.0 assay buffer (80 μ l) or assay buffer containing 0.3 ng/ml of FXIa (80 μ l). LVY- AMC substrate (10 μ l of 2 mM) was added and the fluorescence was monitored (Ex 360 nm/ Em 440 nm) for 1500 seconds. FXIa at 0.3 ng/ml was used as a control. ADAMTS13 activity was significantly increased (by approximately 8-fold)

5 towards LVY-AMC substrate upon treatment of platelets with FXIa. Activity of platelets isolated from PRP of an acquired TTP patient was enhanced by treatment with FXIa to a much lesser extent than those isolated from PRP of a normal individual. This shows that the inhibitory antibodies in TTP plasma block activation of platelet ADAMTS13 by FXIa.

- 10 The activity of FXIa treated platelets towards LVY-AMC was significantly reduced after addition at 1500 seconds of 50 μ l acquired TTP plasma to the reaction mixture, whereas, addition of 50 μ l normal plasma had no significant effect on the activity (Figure 12). These results show that the enhancement of platelet ADAMTS13 activity by FXIa is blocked by anti-ADAMTS13 antibodies. These findings also show that ADAMTS13 activity can be
- 15 enhanced by treatment with proteolytic enzymes.

These findings suggest that ADAMTS13 present on platelets is in a different form than that found in plasma. Results above show that platelet ADAMTS13 appears to have greater enzymatic activity towards peptidyl substrates than plasma ADAMTS13. The finding of

20 proteolytically cleaved ADAMTS13 on platelets may explain the differences in reactivity of plasma and platelet-bound ADAMTS13 towards peptidyl substrates.

Example 11. Measuring ADAMTS13 Antigen in Plasma Using ELISA

An ELISA for measuring ADAMTS13 protein in biological fluids was developed.

- 25 Immulon 4 96-well microtiter plates (Dynex) were coated with goat anti-ADAMTS13 antibody (2 μ g/ml) in 100 μ l of 50 mM MOPS buffer pH 6.0. Plates were washed and blocked with Superblock (Pierce, IN). A PNP sample was serially diluted 1:2 in buffer and 100 μ l was added to microtiter wells. After incubation for 1 hour at 37°C, the plate was washed and 0.5 μ g/ml immunoglobulin purified from plasma obtained from a patient with
- 30 acquired TTP was added to the microtiter wells. After incubation at 37° C for 1 hour, the plate was washed and donkey anti-human Ig-HRP labeled antibody (Jackson Laboratories, ME) (1:1000) was added to the wells. After incubation for 1 hour at 37° C, the plate was washed and 100 μ l TMB substrate (Moss Inc, MD) was added to each well. The plate was

incubated at room temperature for 5 minutes and the reaction was stopped by adding 50 μ l of 0.45 M sulfuric acid. The absorbance at 450 nm was measured. Figure 13 shows the increase in absorbance was linearly proportional to the amount of ADAMTS13-containing plasma added.

5

In another experiment, the amount of ADAMTS13 protein in 24 normal plasma samples was determined using the ELISA method. The results are shown in Figure 14. Using PNP as 100%, the amount of ADAMTS13 in 24 individual normal plasma samples was distributed around the PNP value. This ELISA method can be used to determine the amount of ADAMTS13 in plasma and other biological fluids.

10

Example 12. Inhibition of Recombinant ADAMTS13 Activity by Goat anti-ADAMTS13 Antibody

Tissue culture fluid (5 μ l) from HEK 293 cells transfected with a vector coding for recombinant ADAMTS13 or tissue culture fluid (5 μ l) from mock transfected HEK 293 cells was added to 5 μ g of goat anti-ADAMTS13 antibody (Santa Cruz Biochemicals, Santa Cruz, CA) and 0.8 mM Suc-LLVY-AMC fluorescent substrate in 50 mM Tris-HCl pH 8.0 buffer (85 μ l). The fluorescence (Vmax) was followed in a spectrofluorometric plate reader at Ex 360 nm/ Em 440 nm (Figure 15).

20

ADAMTS13 culture fluid had more fluorescence activity than the mock transfected culture fluid. The goat anti-ADAMTS13 antibody inhibited the fluorescence from the ADAMTS13 fluid but not from the tissue culture fluid from mock transfected cells. These results show that the fluorescence activity from the fluid from mock transfected cells is not due to ADAMTS13.

25

Example 13. Inhibition of Recombinant ADAMTS13 Activity by Acquired TTP Plasma

Plasma from patients with acquired TTP ("acquired TTP plasma") contains an inhibitory antibody against ADAMTS13. Figure 16 shows that the addition of TTP plasma to tissue culture supernatant containing recADAMTS13 inhibited the generation of a fluorescence signal when Suc-LLVY-AMC was used as a substrate. The amount of inhibition of fluorescence signal was dependent on the amount of TTP plasma added. Plasma from

30

healthy subjects ("normal plasma") did not significantly inhibit ADAMTS13 activity, as compared to acquired TTP plasma, demonstrating the ADAMTS13 activity was specifically inhibited by the acquired TTP plasma. These studies also show that antibodies present in acquired TTP plasmas block hydrolysis of the fluorescent Suc-LLVY-AMC substrate by recombinant ADAMTS13.

Example 14. Inhibition of ADAMTS13 Activity on Isolated Platelets by Anti-ADAMTS13 Antibodies

One ml of PRP was centrifuged at 10,000 rpm and the platelets in the pellet were washed with 50 mM Tris-HCl pH 8.0 buffer. The platelets were suspended in 200 µl of assay buffer. Isolated platelets (20 µl) were added to 70 µl of various anti-ADAMTS13 antibodies and incubated at room temperature for 15 minutes. The G1 and G2 goat antibodies (Santa Cruz Biochemicals, Santa Cruz, CA) were used at 200 µg/ml; the rabbit antibody against the C-terminal fragment of ADAMTS13 (from Dr. Ginsburg) was used at 5.5 mg/ml. Purified immunoglobulin (Ig) from acquired TTP plasma was used at a concentration of 4 mg/ml. Ninety µl of 10mM Tris-HCl pH 8.0 buffer and 10 µl of 8 mM LVY-AMC were added and the fluorescence was measured over time as above. All four anti-ADAMTS13 specific antibodies inhibited the activity of normal platelets (Figure 17). These findings indicate that the activity in platelets was due to ADAMTS13 cleaving the LVY-AMC substrate.

Example 15. A Method for Measuring Anti-ADAMTS13 Antibodies in Plasma Using Isolated Platelets

Detection of anti-ADAMTS13 autoantibodies was performed using isolated platelets as a source of ADAMTS13. Isolated platelets (prepared from 200 µL of normal PRP) were incubated with 200 µL pooled normal plasma (PNP) or acquired TTP plasma. The mixtures were incubated at 37°C for 30 minutes. Fifty µl were removed from each reaction mixture and added to 130 µl of 50 mM Tris-HCl pH 8.0 buffer and 20 µL of 8 mM LVY-AMC substrate. The reaction mixtures were incubated for 30 minutes at 37° C for one hour and fluorescence was monitored in a spectrofluorometric plate reader (Ex 360 nm/ Em 440 nm). The platelets incubated with normal plasma had high fluorescence signal (indicating high ADAMTS13 activity), whereas the platelets incubated with acquired TTP plasma had low fluorescence signal (indicating low ADAMTS13 activity) (Figure 18). These results show

that anti-ADAMTS13 autoantibodies were present in the acquired TTP plasma, but not in the normal plasma, and that autoantibodies in plasma from a patient with acquired TTP can be detected using this method. Other fluorescent ADAMTS13 substrates can be substituted for LVY-AMC. This method can be used to distinguish between congenital TTP and
5 acquired TTP.

Figure 19 shows that the level of inhibition of ADAMTS13 activity on platelets is dependent on the amount of anti-ADAMTS13 autoantibodies used in the assay, and thus the anti-ADAMTS13 activity. Plasma from an acquired TTP patient was diluted to different
10 amounts (10%, 20% and 40%) in normal plasma and incubated with isolated platelets in a total volume of 90 μ l for 15 minutes. Ten μ l of 8 mM LVY-AMC substrate was added and the fluorescence was determined after incubation at 37°C for 1 hour. The inhibition of ADAMTS13 activity by TTP plasma was dependent upon the amount of TTP plasma used in the assay.

The amount of fluorescence generated over time in the assay is dependent upon the amount of platelets used in the assay. As shown in Figure 20, a higher fluorescent signal was generated in the control (normal plasma without anti-ADAMTS13 antibodies) using more platelets. The addition of acquired TTP plasma, containing ADAMTS13 antibodies, almost
20 completely inhibited ADAMTS13 activity, regardless of the amount of platelets in the assay.

Example 16. Detection and Measurement of ADAMTS13/FXI Complexes in Plasma

An assay was developed for measuring the presence of ADAMTS13/FXI complexes by
25 ELISA analysis. A standard curve was generated using PNP (Saturn Biomedical), diluted 1:4 in ECD buffer (PBS/3% BSA/gentamicin), and then serially diluted 1:2 in ECD buffer. Assays were performed in duplicate, using 100 μ l of each standard dilution in Immulon 4 HBX 96-well microtiter plates (ThermoLabsystems, Franklin, MA) that were coated with goat anti-human ADAMTS13 antibodies (SC21510; Santa Cruz Biotechnology, Santa Cruz,
30 CA) at a concentration of 1 μ g/ml in 3-(N-morpholino)propanesulfonate (MOPS) coating buffer (0.1 M MOPS, 0.15 M NaCl, 0.05 M CaCl_2 , 0.066 M Trehalose, 0.02% NaN_3 , pH 7.4). Microtiter plates were blocked with SuperBlock (Pierce Chemical Co., Indianapolis, IN).

Standards and diluted samples were incubated in coated microwells for 2 hours at room temperature, with mixing. The plate was then washed four times with wash buffer (PBS + 1% Tween, pH 7.4). An anti-FXI antibody labeled with HRP was diluted to 1 µg/ml in 7% normal goat serum in ECD buffer, and then 100 µl of the diluted detection antibody was added to each well. The antibody was allowed to bind for one hour at room temperature. Following incubation with the detection antibody, the plate was washed four times in wash buffer. Tetramethylbenzidine HRP substrate (TMB-HRP; 100 µl) was then added to the microwells. After 15 minutes, the reaction was terminated with 0.5 N sulfuric acid. The optical density of the mixture was then read in a spectrophotometer at 450 nm. The standard curve generated is shown in Figure 21.

Example 17. Binding of Recombinant ADAMTS13 to FXI-Coated Plates

Binding of recombinant ADAMTS13 to immobilized FXI was measured using microplates coated with human FXI at a concentration of 1 µg/ml. Recombinant ADAMTS13 in solution was added to the FXI-coated microwells and incubated for 1 hour. ADAMTS13/FXI complexes were measured using ELISA. Specifically, after incubation with recombinant ADAMTS13, plates were washed with PBS + 1% Tween, followed by incubation for 1 hour with anti-ADAMTS13 TSP5-7 rabbit polyclonal antibodies (1 µg/ml). Plates were washed again in PBS + 1% Tween, followed by addition of a murine anti-rabbit IgG antibody conjugated to HRP. The detection antibody was incubated for an hour at room temperature. After washing the excess detection antibody from the plates, the TMB substrate was added, incubated for 10 minutes, after which 0.5 M sulfuric acid was added to terminate the reaction. The optical density of the mixture was measured at 450 nm on a spectrophotometer (Figure 22). The results show that recombinant ADAMTS13 can form a stable complex with FXI.

Example 18. Measurement of ADAMTS13-FXI Complexes in Acquired TTP Plasma

ADAMTS13/FXI complexes in plasma from 23 normal individuals and 7 patients with acquired TTP were measured as described in Example 16. Table 1 summarizes the mean levels of ADAMTS13/FXI in normal plasma and TTP plasma. The support the conclusion that ADAMTS13/FXI complex formation in normal plasma is higher than in acquired TTP plasma.

Table 1: Comparison of ADAMTS13 Antigen in Normal and TTP Plasma

	% PNP (mean $\pm$ STD)	N
Normal Plasma	58.8 $\pm$ 67	23
Acquired TTP	20.2 $\pm$ 18 (p<0.12)	7

Example 19. Measurement of ADAMTS13/FXI Complexes in FXI-Deficient Plasma

Complex formation was measured in plasma from patients with a congenital FXI deficiency using the ELISA of Example 16. The results show a significantly lower level of ADAMTS13/FXI complexes in FXI-deficient plasma than in normal plasma. As Figure 23 shows, the amount of complexes in FXI-deficient plasma are approximately equivalent to 2.1% of the amount in normal plasma.

Formation of ADAMTS13/FXI complexes was measured after addition of FXI (Enzyme Research Lab, Canada) to FXI-deficient plasma diluted 1:8 in ECD. Differing amounts of FXI were added to FXI-deficient plasma incubated for 30 minutes to promote complex formation. The plasma containing newly formed ADAMTS13/FXI complexes were then added to anti-ADAMTS13 antibody-coated microwells and quantified, as described in Example 16. Figure 24 shows that increasing amounts of ADAMTS13/FXI complexes were formed upon addition of increasing amounts of FXI to the FXI-deficient plasma.

Various modifications and variations of the described products and methods of the invention will be apparent to those skilled in the art without departing from the scope and spirit of the invention. Although the invention has been described in connection with specific preferred embodiments, it should be understood that the invention as claimed should not be unduly limited to such specific embodiments. Indeed, various modifications of the described modes for carrying out the invention which are obvious to those skilled in chemistry, biology or related fields are intended to be within the scope of the following claims.

CLAIMS

We claim:

1. A method for detecting ADAMTS13/FXI complexes in a sample comprising:
 - a) binding an anti-ADAMTS13 antibody to a solid phase;
 - b) adding the sample to the solid phase, wherein ADAMTS13/FXI complexes present in the sample binds to the antibody;
 - c) adding an anti-FXI antibody to the solid phase, wherein the FXI antibody binds to FXI in ADAMTS13/FXI complexes; and
 - d) detecting ADAMTS13/FXI complexes by direct or indirect immunolabelling of the anti-FXI antibody.
2. The method of claim 1, wherein the sample is selected from the group consisting of a biological fluid, whole blood, plasma, platelet rich plasma (PRP), platelet poor plasma (PPP), pooled normal plasma (PNP), washed platelets and tissue culture supernatant.
3. The method of claim 1, wherein the solid phase is a membrane, plate, microwell or bead.
4. The method of claim 1, wherein detecting ADAMTS13/FXI complexes is by direct immunolabelling of the anti-FXI antibody.
5. The method of claim 4, wherein the anti-FXI antibody is labeled with horse radish peroxidase.
6. The method of claim 1, wherein detecting ADAMTS13/FXI complexes is by indirect immunolabelling of the anti-FXI antibody.
7. The method of claim 6, wherein the anti-FXI antibody is raised in a first species and wherein a labeled antibody raised in a second species against antibodies from the first species is added to the solid phase and detected.
8. A method for measuring the amount of ADAMTS13/FXI complexes in a sample comprising the method of claim 1 and further comprising:
 - e) quantifying anti-FXI antibody detected, thereby measuring the amount of ADAMTS13/FXI complexes in the sample.
9. A method for diagnosing thrombotic thrombocytopenia purpura (TTP) in a subject comprising

- a) measuring the amount of ADAMTS13/FXI complexes in a test sample from the subject according to the method of claim 8; and
- b) comparing the amount of ADAMTS13/FXI complexes in the test sample to the amount of ADAMTS13/FXI complexes in a control sample having normal ADAMTS13 activity;

wherein TTP is diagnosed by a reduced amount of ADAMTS13/FXI complexes in the test sample compared with the control sample.

10. The method of claim 9, wherein the test sample is selected from the group consisting of whole blood, plasma, platelet rich plasma (PRP), platelet poor plasma (PPP), pooled normal plasma (PNP) and washed platelets.

11. The method of claim 9, wherein the solid phase is a membrane, plate, microwell or bead.

12. The method of claim 9, wherein detecting ADAMTS13/FXI complexes is by direct immunolabelling of the anti-FXI antibody.

13. The method of claim 12, wherein the anti-FXI antibody is labeled with horse radish peroxidase.

14. The method of claim 9, wherein detecting ADAMTS13/FXI complexes is by indirect immunolabelling of the anti-FXI antibody.

15. The method of claim 14, wherein the anti-FXI antibody is raised in a first species and wherein a labeled antibody raised in a second species against antibodies from the first species is added to the solid phase and detected.

16. A kit for detecting ADAMTS13/FXI complexes in a sample comprising:

- (i) a solid phase coated with an anti-ADAMTS13 antibody; and
- (ii) an anti-FXI antibody.

17. The kit of claim 16, wherein the anti-FXI antibody is labeled.

18. The kit of claim 17, wherein the FXI antibody is labeled with horse radish peroxidase.

19. The kit of claim 18, further comprising a substrate for horse radish peroxidase.

20. The kit of claim 16, further comprising one or more components selected from the group consisting of a standard sample, a positive control and a wash buffer.

Figure 1

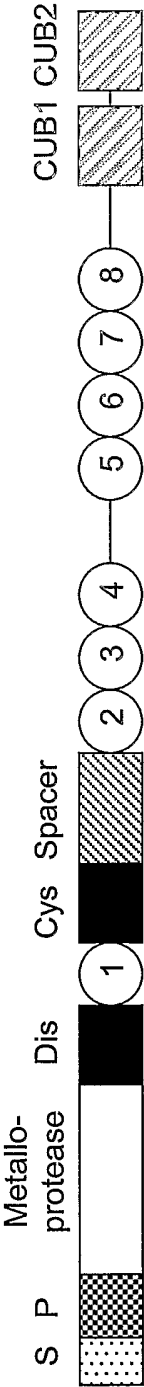


Figure 2

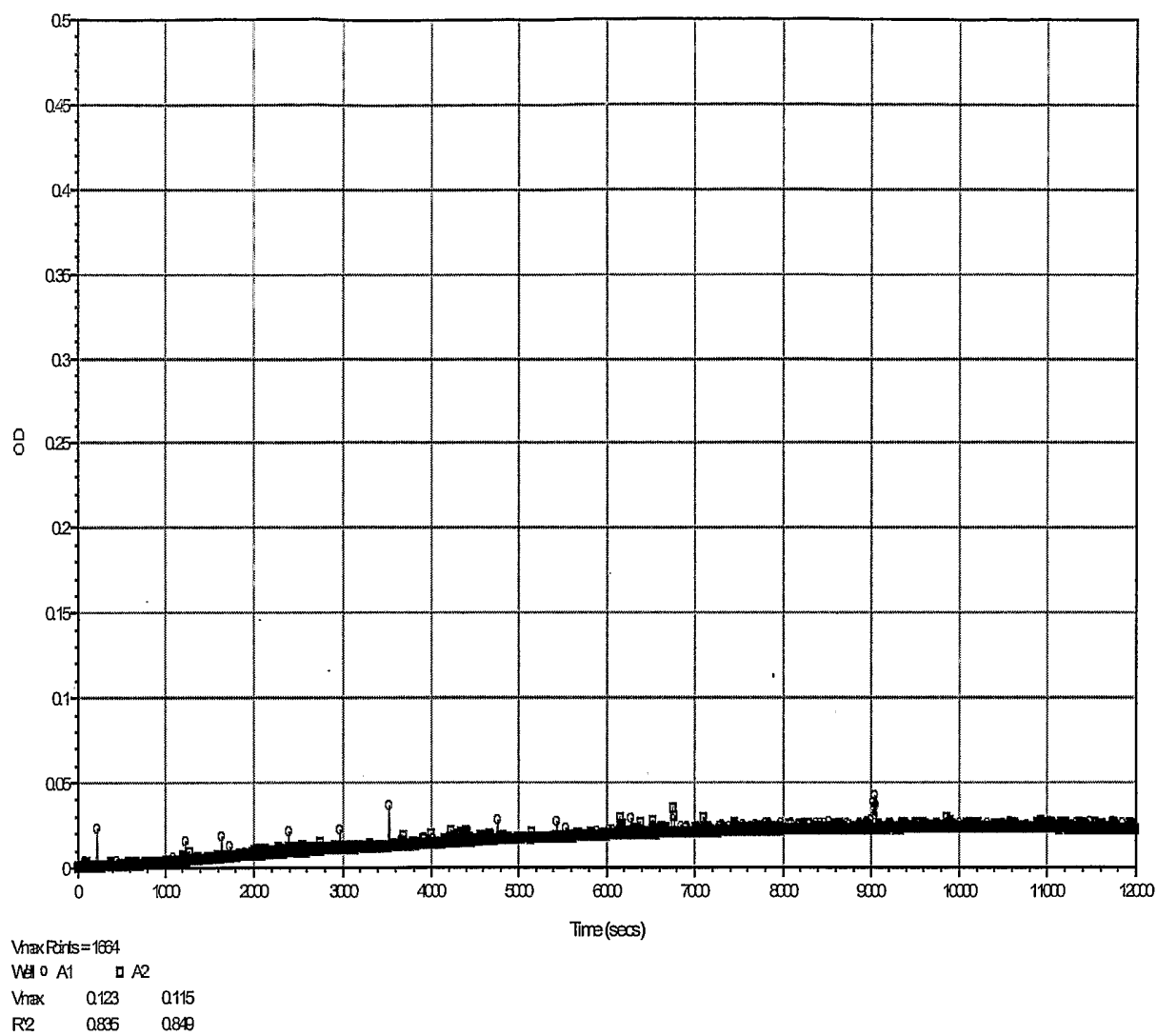


Figure 3

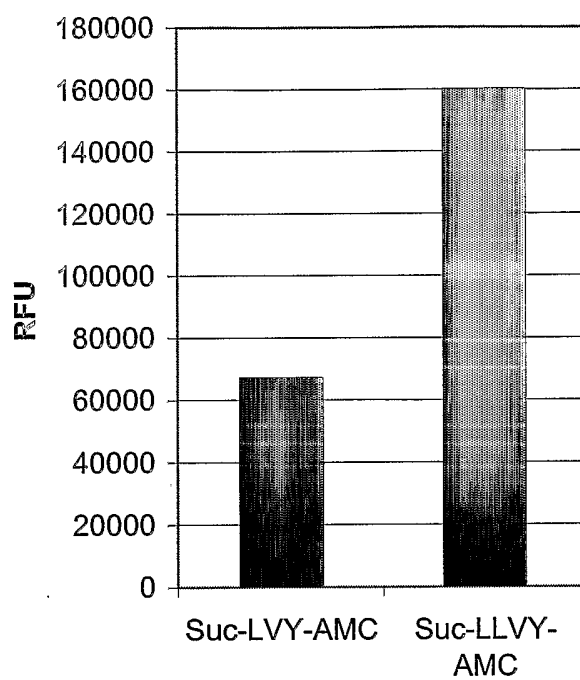


Figure 4

Cleavage of FRET substrate by Platelet AD13

NH₂-Arg-Lys(DABCYL)-
NLVYMTGD(EDANS)-Arg-COOH

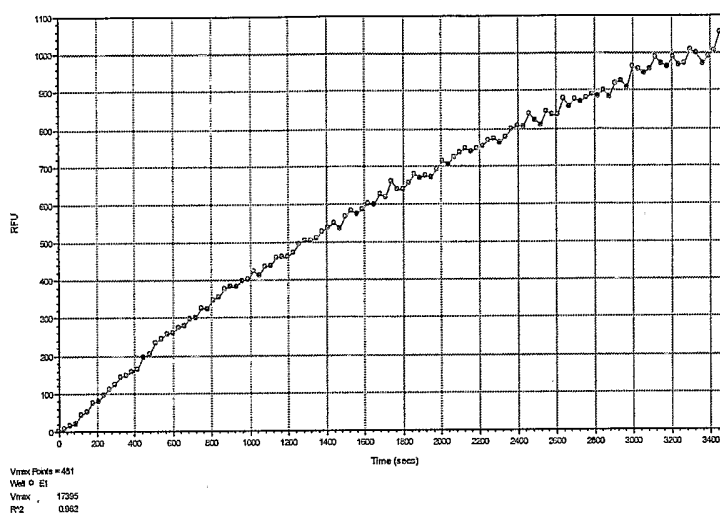


Figure 5

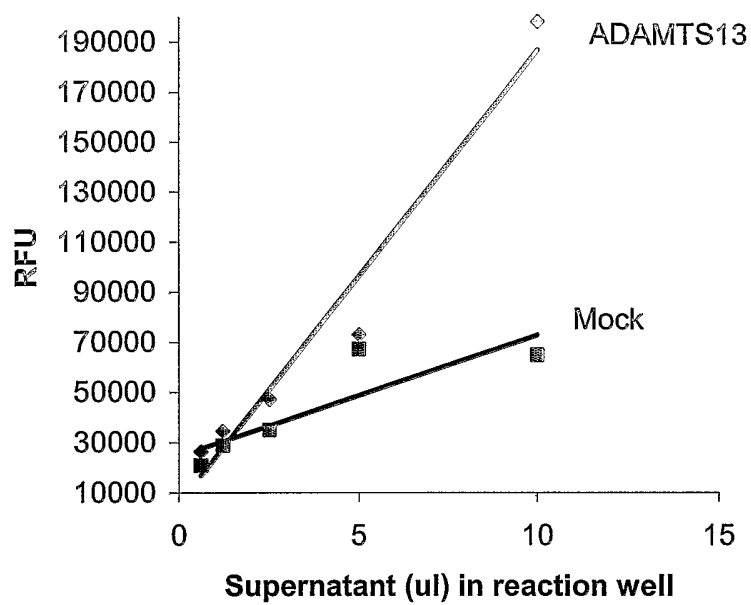


Figure 6

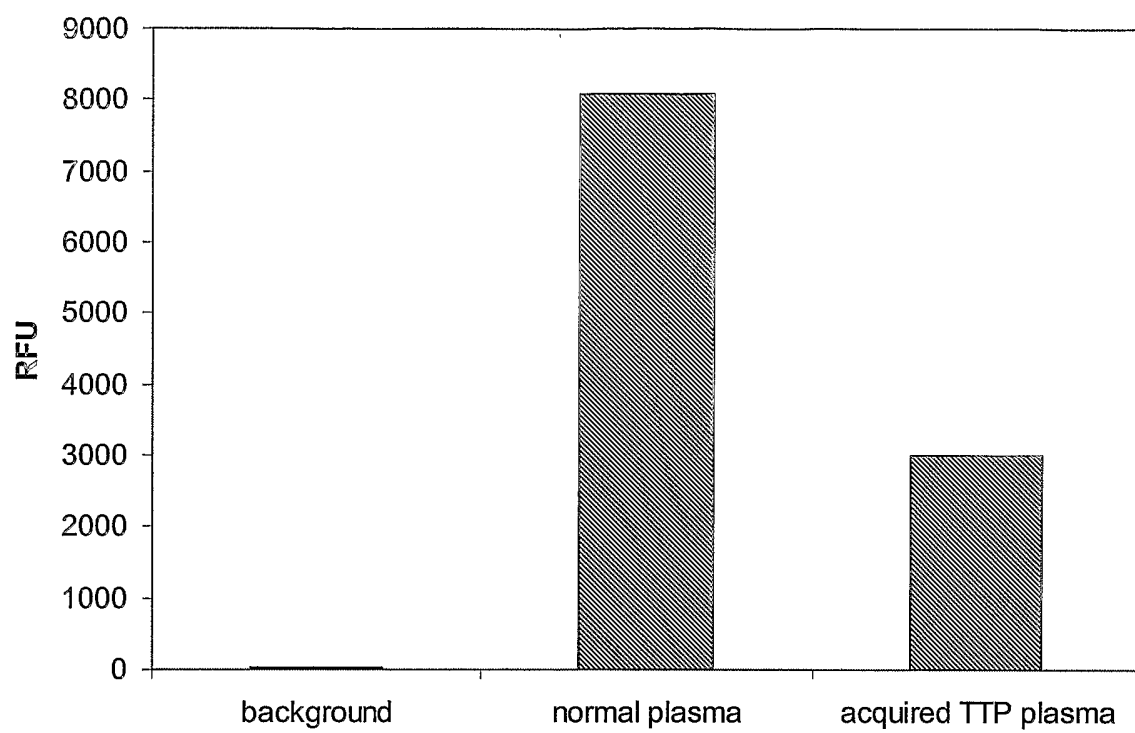


Figure 7

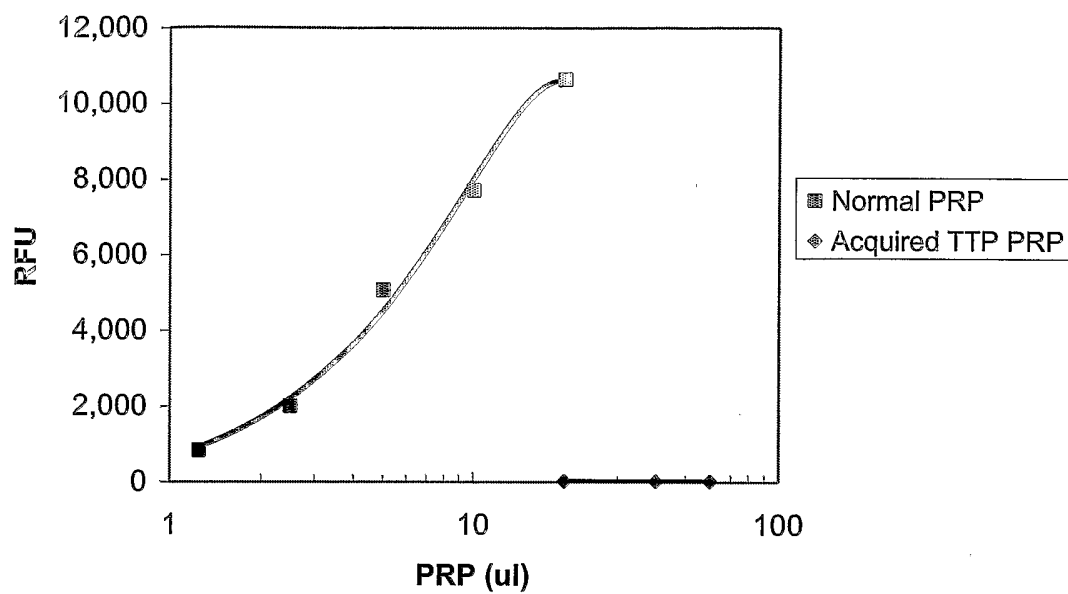


Figure 8

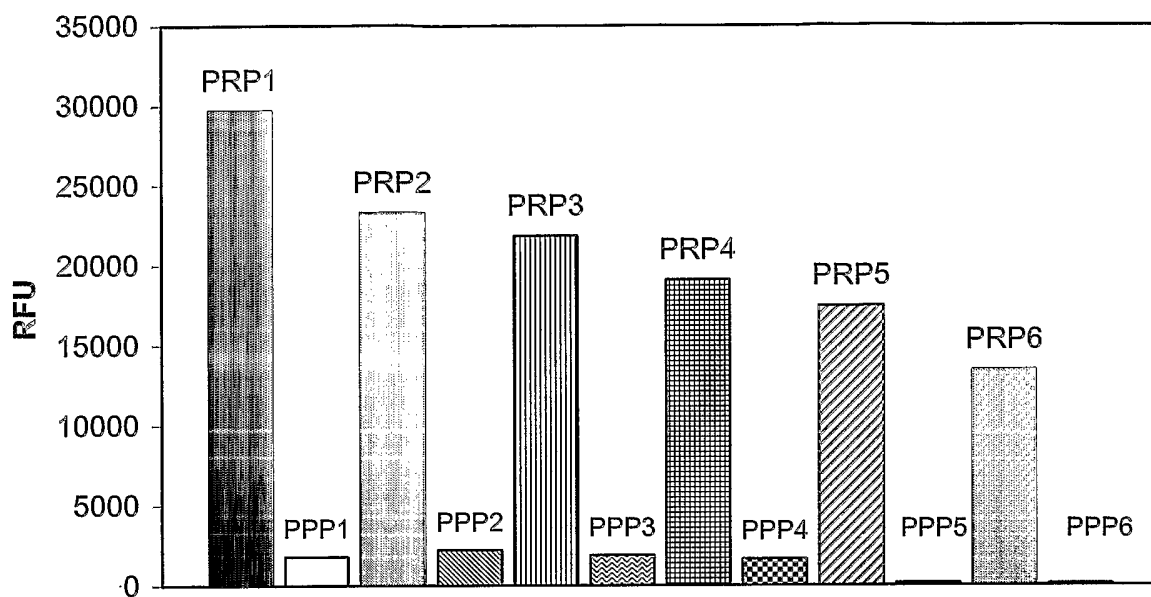


Figure 9

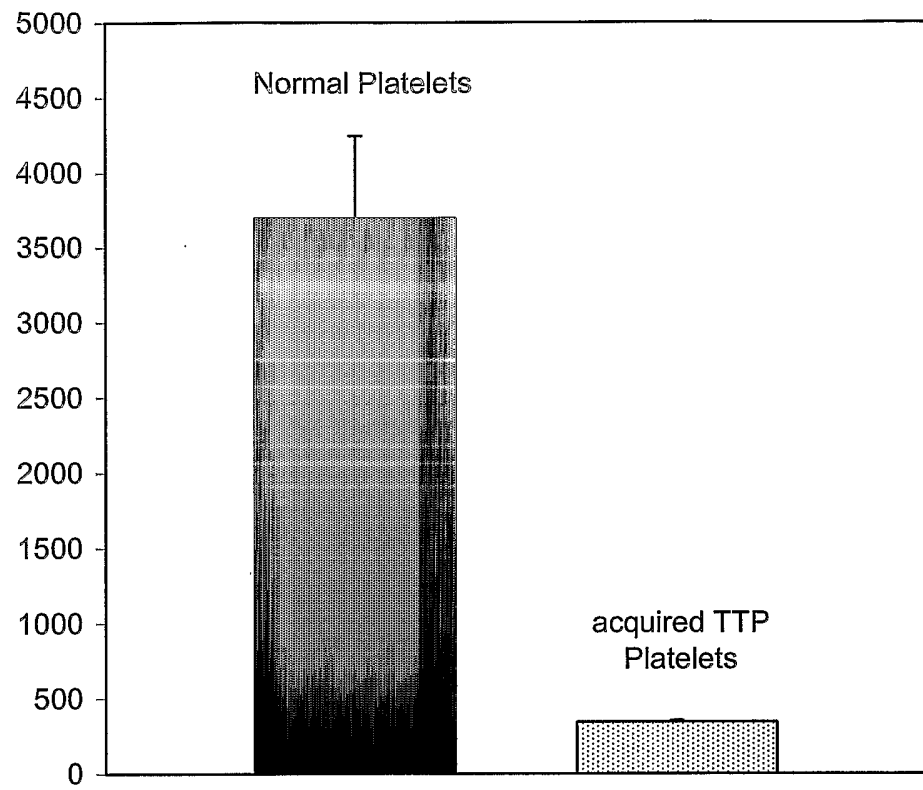


Figure 10

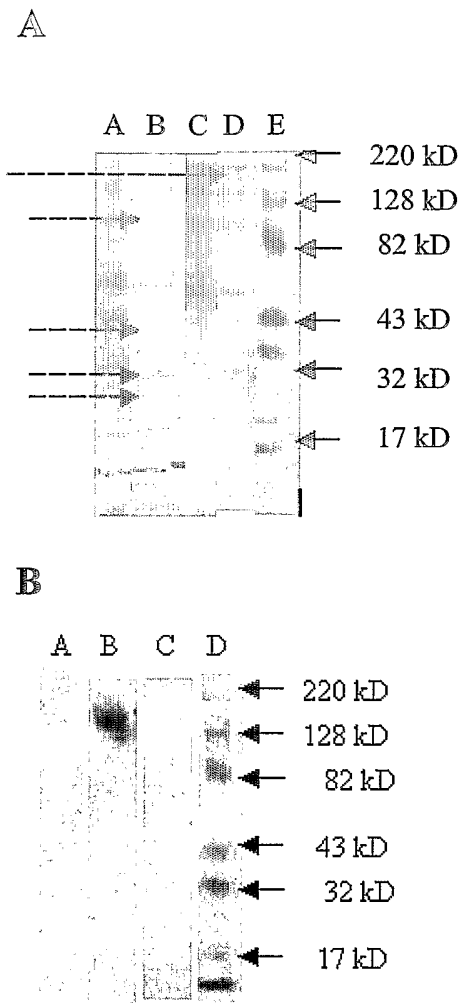


Figure 11

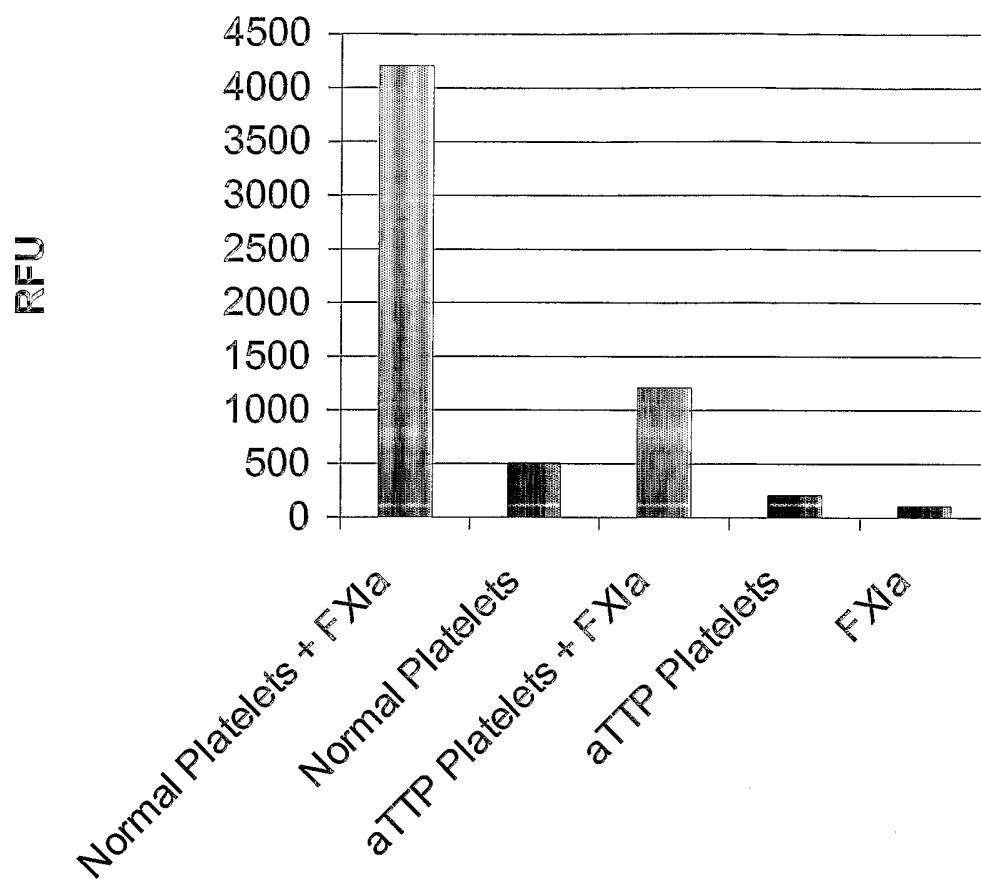


Figure 12

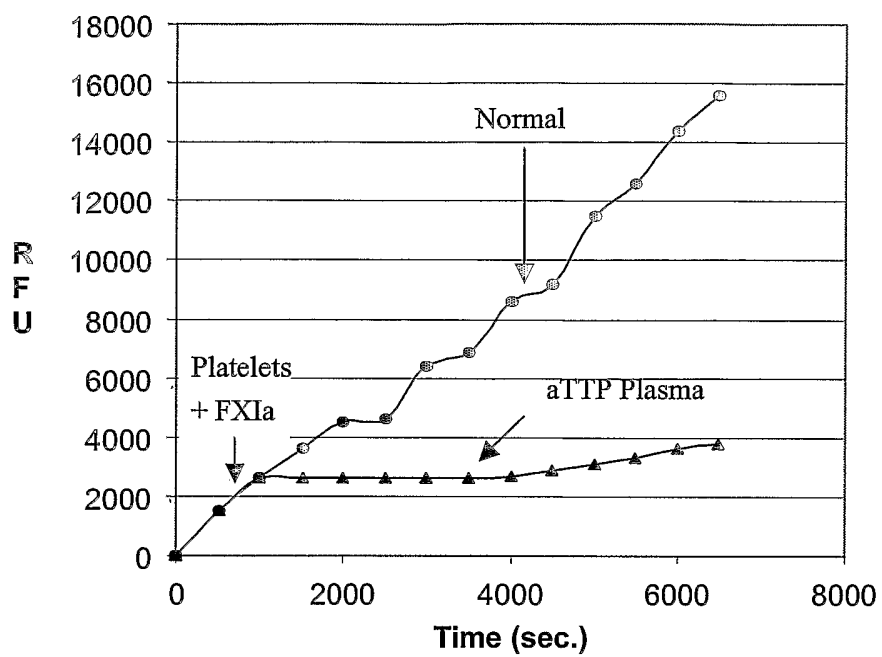


Figure 13

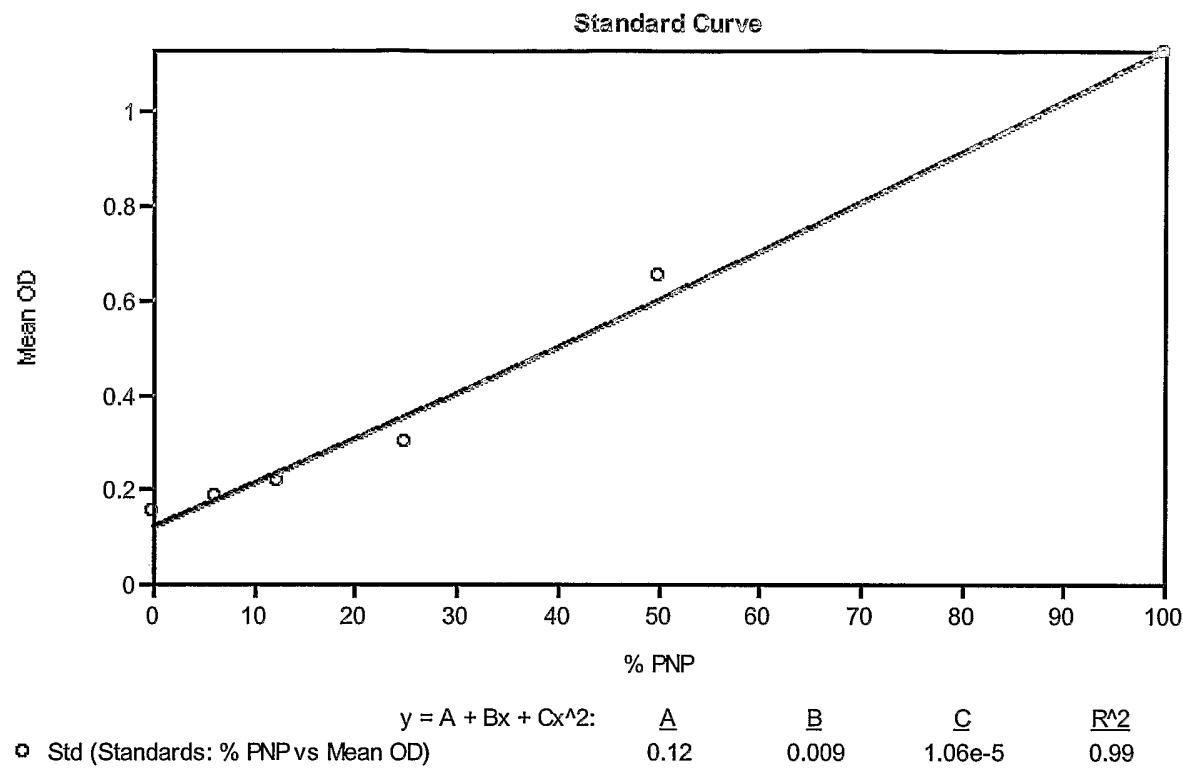


Figure 14

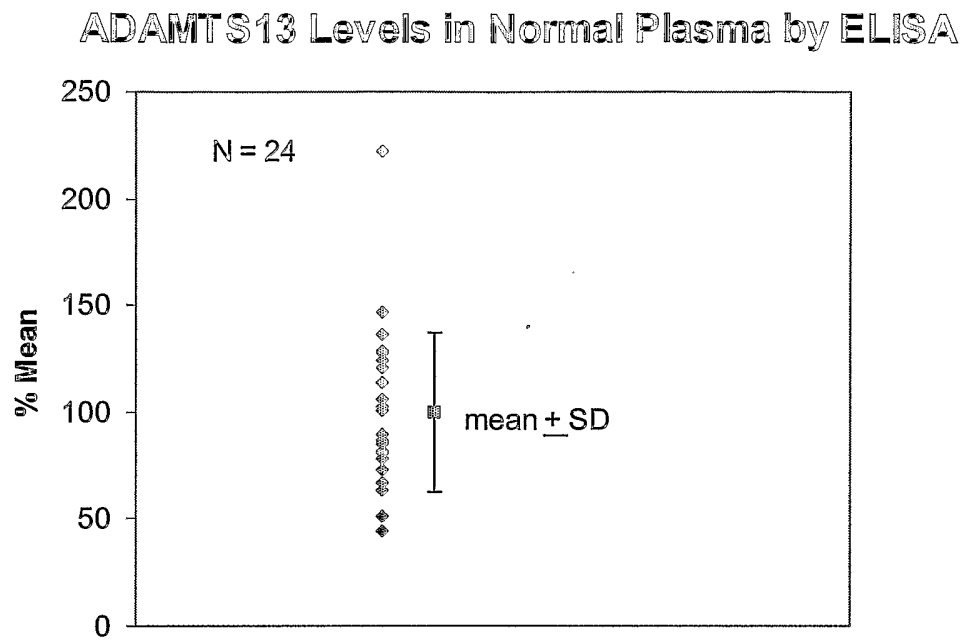


Figure 15

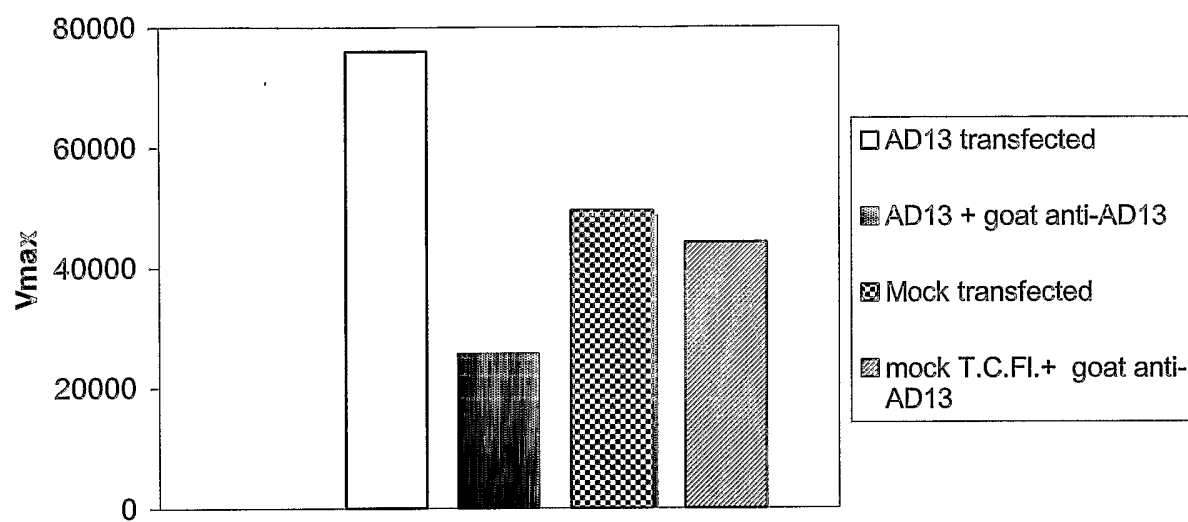


Figure 16

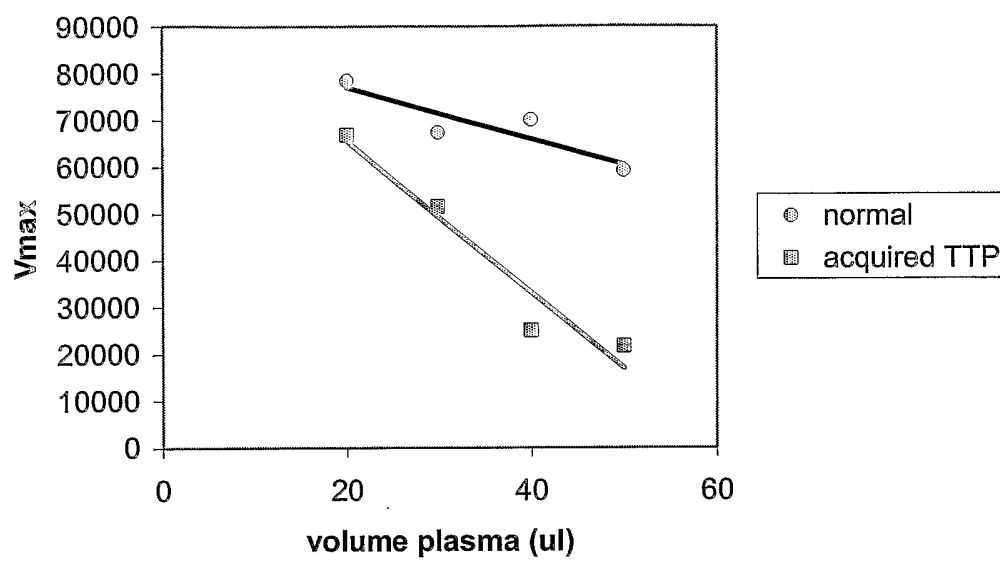


Figure 17

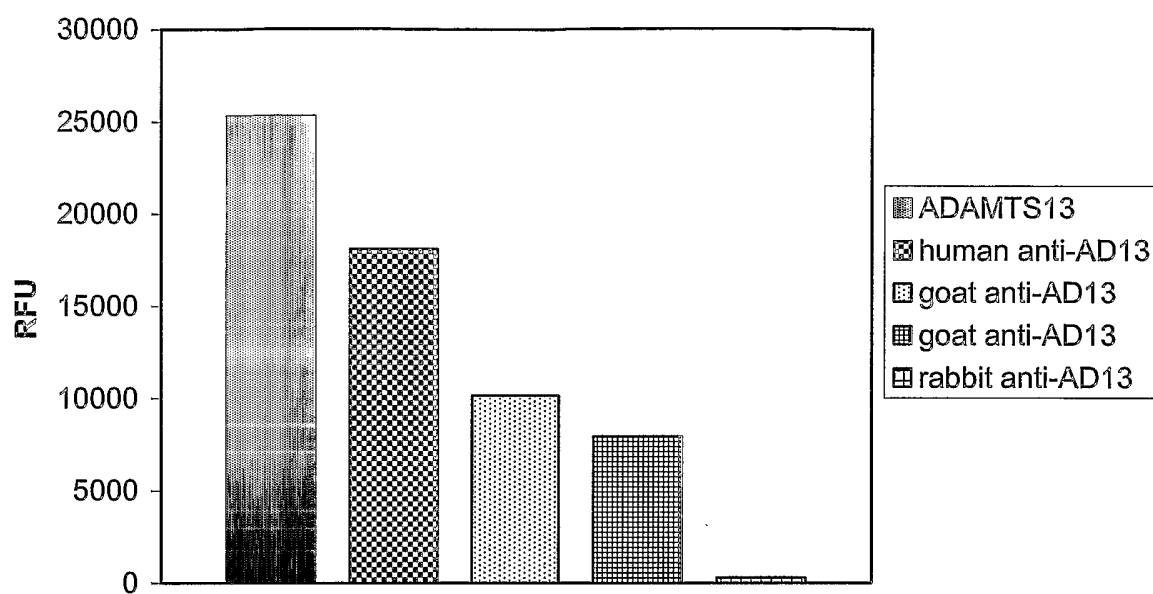


Figure 18

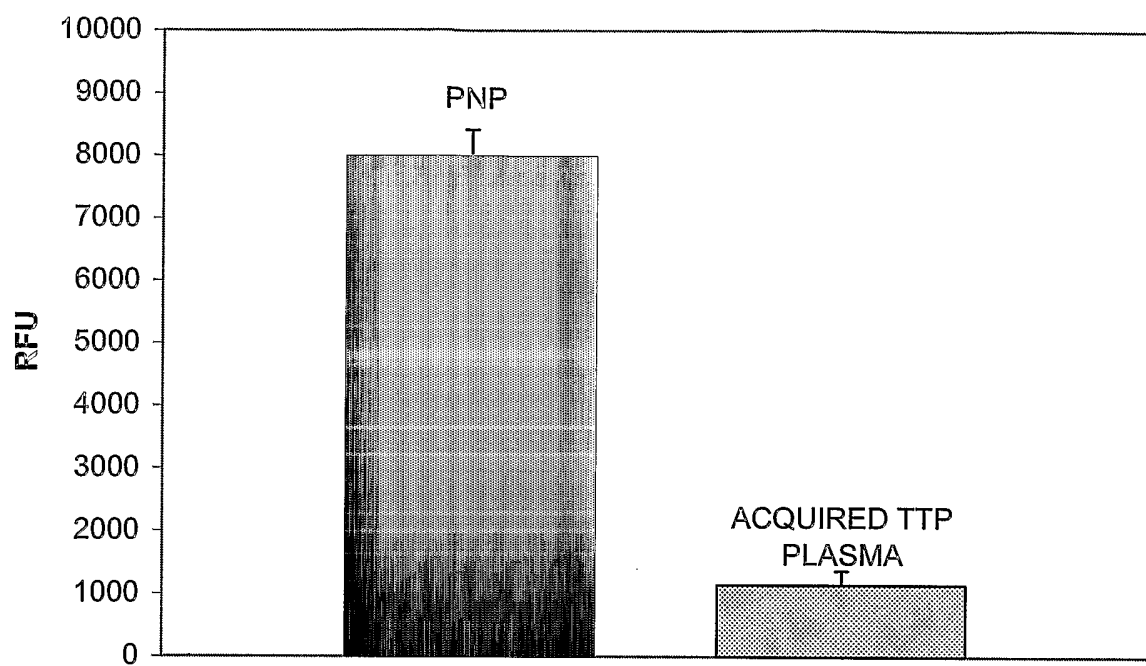


Figure 19

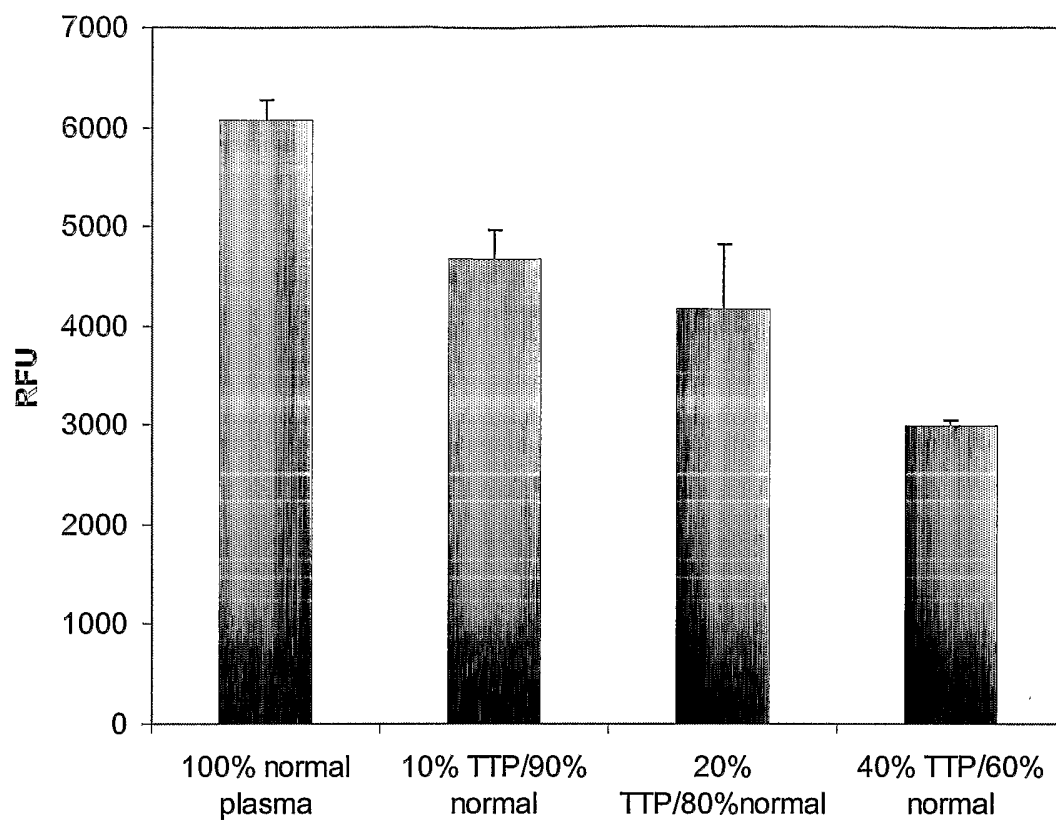


Figure 20

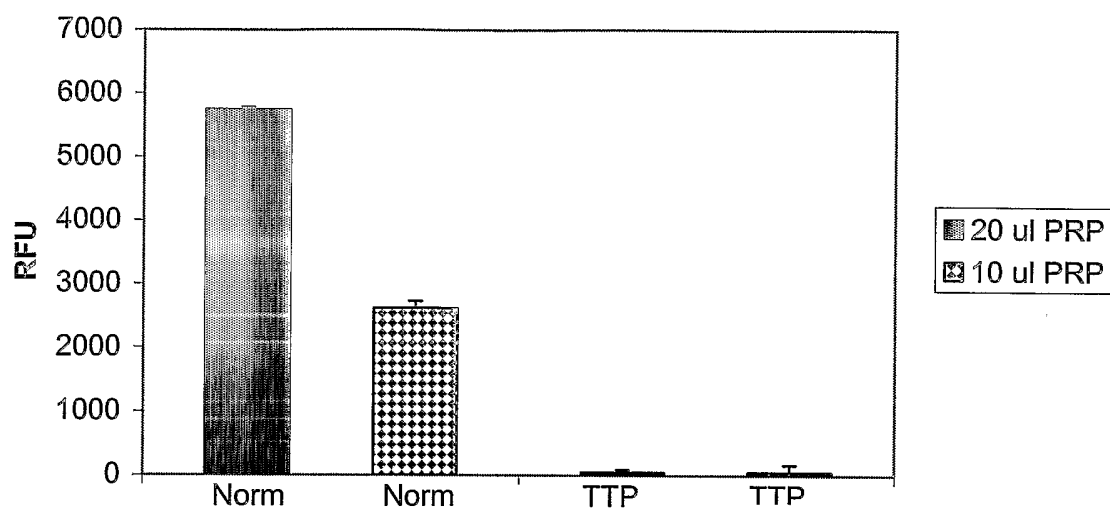
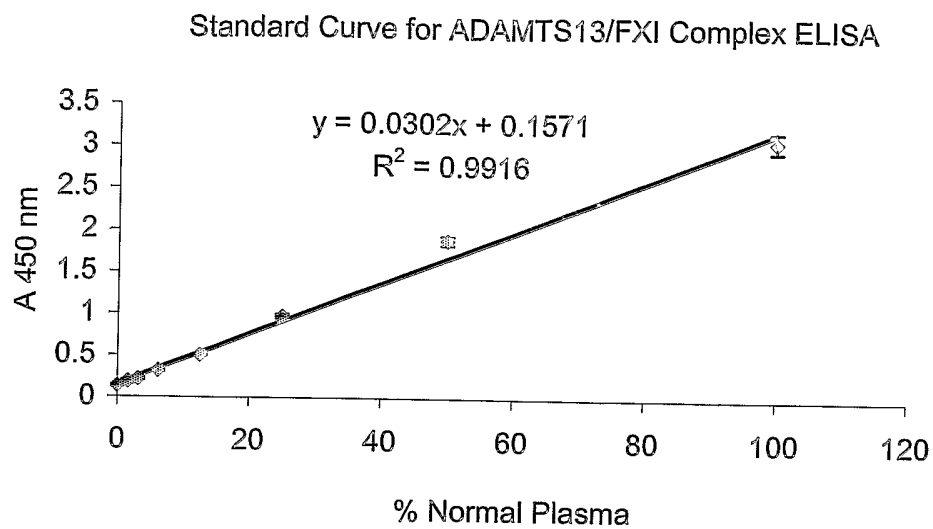


Figure 21**Figure 22**

Binding of recombinant ADAMTS13 to FXI-coated
Microtiter plate

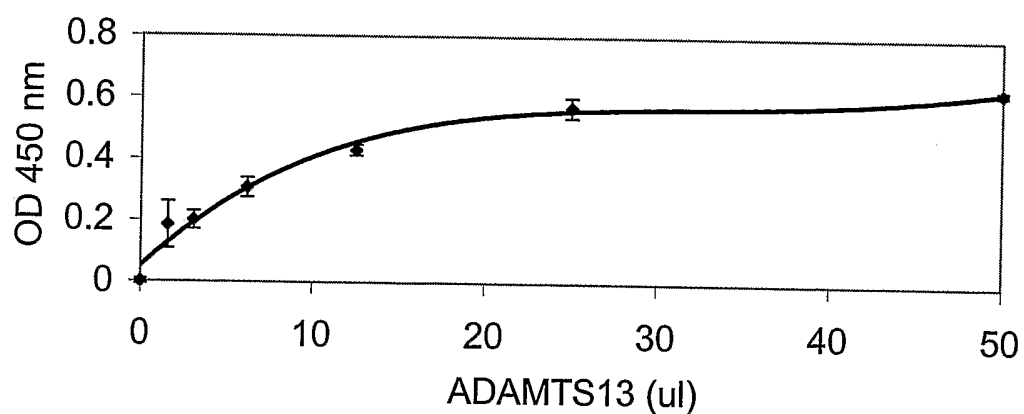


Figure 23

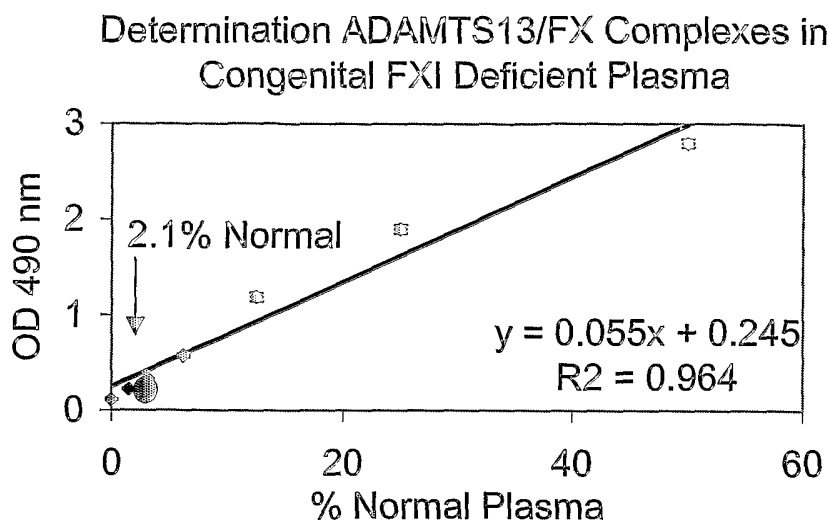


Figure 24

