Vitronectin (S Protein) Augments the Functional Activity of Monocyte Receptors for IgG and Complement C3b

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An arginine-glycine-aspartic acid sequence (RGD in the single letter code for amino acids) is present in the cell attachment site of both vitronectin and fibronectin. Inasmuch as fibronectin and synthetic peptides containing RGD enhance ingestion of opsonized particles by monocytes, we investigated the effects of vitronectin on phagocytosis by monocytes of sheep erythrocytes bearing IgG (EA) or complement C3b (EC3b). Peripheral blood monocytes were isolated by countercurrent elutriation and allowed to adhere to slides that had been coated with either vitronectin or fibronectin. Next, EA or EC3b were incubated with the adherent monocytes, and phagocytosis was subsequently quantified. Vitronectin caused the same dose dependent increase in phagocytosis as fibronectin. The augmentation of phagocytosis of EA induced by vitronectin could be inhibited by the F(ab')2 fragments of anti-vitronectin IgG but not by preimmune F(ab')2. The maximum phagocytosis of EA induced by vitronectin could not be enhanced by the addition of fibronectin, suggesting that vitronectin and fibronectin act on the same population of monocytes and that the two proteins stimulate the same mechanism through which the enhanced phagocytosis is mediated. Fibronectin and vitronectin caused a tenfold increase in the attachment of EC3b to monocytes, but phagocytosis was augmented minimally. These studies demonstrate that vitronectin modulates interactions between monocytes and opsonized particles.

MATERIALS AND METHODS

Buffers and reagents. The following buffers were used: veronal-buffered saline (VBS); VBS containing 0.1% gelatin (GVB); GVB containing 0.15 mmol/L CaCl2 and 1 mmol/L MgCl2 (GVB+); GVB containing 0.15 mmol/L NiCl2 (GVB-Ni); GVB containing 15 mmol/L EDTA (GVB-EDTA); phosphate-buffered saline, 10 mmol/L phosphate, 150 mmol/L NaCl, pH 7.4 (PBS); Hanks balanced salt solution (HBSS) (M. A. Bioproducts, Walkersville, MD); HBSS containing 0.5% human serum albumin (HBSS/Al); elutriation buffer (EB), 150 mmol/L NaCl, 3 mmol/L KCl, 2 mmol/L KH2PO4, 8 mmol/L Na2HPO4, 6 mmol/L dextrose, 0.1% human serum albumin, and 1 mmol/L EDTA. The following reagents were purchased from commercial vendors: Ficoll-Hypaque, Pharmacia Fine Chemicals, Division of Pharmacia, (Piscataway, NJ); Dextran 70, McGraw Laboratories (Irvine, CA); RPMI 1640, Sigma Chemical (St Louis, MO); penicillin and streptomycin, Flow Laboratories (McClean, VA); human serum albumin, Sigma; gelatin, J.T. Baker Chemical (Phillipsburg, NJ); and glutaraldehyde, Electron Microscopy Sciences (Ft Washington, PA).

Proteins and antibodies. Vitronectin,14 fibronectin,15 C3,14 factor B,17 factor D,19 and cobra venom factor (CVF)18 were isolated using previously published methods. Rabbit anti-sheep erythrocyte IgG, rabbit anti-fibronectin IgG, and the F(ab')2 fragments of rabbit anti-fibronectin were purchased from Cooper Biomedical (Malvern, PA). Antibody to vitronectin was raised in rabbits, and the IgG was isolated using 5% caprylic acid.18 Nonimmune IgG was prepared by isolating the IgG from the sera of rabbits prior to immunization. The F(ab')2 fragments of the immune and nonimmune IgG were prepared with immobilized pepsin (Pierce Chemical, Rockford, IL). After incubation of the IgG with the immobilized pepsin according to the suggestions of the manufacturer, the reaction mixture was centrifuged, and the supernate was chromatographed on Sephacryl S-200 (Pharmacia). The fractions containing the F(ab')2 fragments [determined by sodium dodecyl sulfate polyacrylamide gel electrophoresis (SDS-PAGE)] were pooled and applied to a column of...
Protein A-Sepharose CL 4B (Sigma Chemical). The unbound protein was collected, and purity was assessed by SDS-PAGE. Affinity-purified anti-C3c\(^{29}\) was a gift of Dr Gordon D. Ross (University of North Carolina School of Medicine, Chapel Hill).

Human IgG was isolated using 5% acrylamide. After dialysis, the IgG was applied to a column of Protein A-Sepharose. The column was extensively washed with PBS, and the IgG was eluted using 0.1 mol/L glycine, pH 3.0. The IgG was immediately dialyzed against PBS. Protein concentrations for C3,\(^{18}\) factor B,\(^{18}\) CVF,\(^{18}\) and IgG\(^{18}\) were determined spectrophotometrically. The concentrations of vitronectin and fibronectin were determined by Bio-Rad Protein Assay (Bio-Rad, Richmond, CA) using bovine IgG as the standard. Monoclonal anti-C3c and rabbit anti-sheep erythrocyte IgG were radiolabeled using IODO-GEN (Pierce Chemical) as previously described.\(^{17}\)

**SDS-PAGE and Western blots.** SDS-PAGE was performed under reducing conditions using a 6% to 12% gradient gel as previously described.\(^{21}\) A modification of the method of Towbin et al.\(^{23}\) was used for the immunoblotting experiments. Peroxidase-conjugated affinity-purified goat anti-rabbit (Fab\(^2\)) (Tago, Burlingame, CA) was used as the second antibody, and antibody binding was detected by incubation with 50 mg diaminobenzidine (Sigma) and 50 \(\mu\)L 30% \(\text{H}_{2}\)O\(_2\).

**Preparation of EA.** Sheep erythrocytes were washed three times in GVB\(^2\) and resuspended to \(1 \times 10^8/\text{mL}\). One milliliter of cells was incubated at 37°C with 1 mL 1:4000 dilution of rabbit anti-sheep erythrocyte IgG. After 30 minutes, the cells were washed three times and resuspended to either 8 \(\times 10^8/\text{mL}\) or 1.6 \(\times 10^9/\text{mL}\). Using radiolabeled rabbit anti-sheep IgG, we estimated that the EA, prepared as described above, bore \(4,800\) molecules of IgG per erythrocyte. EA were prepared and used on the same day that the phagocytosis experiments were performed.

**Preparation of EC3b.** Sheep erythrocytes bearing C3b were prepared using purified components of the alternative pathway of complement according to a modification of the method of Ross et al.\(^{20}\) A stable fluid-phase C3 convertase (CVFBB) was created by incubating purified CVF with factor B and factor D as previously described.\(^{22}\) Sheep erythrocytes were washed three times with GVB-EDTA and resuspended to \(1 \times 10^8/\text{mL}\). Two milliliters of cells were centrifuged, and the supernate was aspirated as completely as possible without disturbing the cell pellet. C3b was initially deposited on the surface of sheep erythrocytes by incubating the cells with 100 \(\mu\)L CVFBB complexes and 1 mg C3 at 37°C. After 30 minutes, the cells were washed three times in GVB-Ni. After the last wash, the supernate was aspirated as completely as possible. Next, amplification C3 convertases (stabilized with nickel) were created on the cell surface, by incubating 50 \(\mu\)g factor B and 25 \(\mu\)L factor D with the pellet at 37°C. After 3 minutes, the cells were washed once in GVB-Ni, 100 \(\mu\)g of C3 was added to the cell pellet, and the mixture was incubated at 37°C for 20 minutes. Next, the cells were washed once in GVB-NI and twice in GVB-EDTA, and incubated at 37°C. After 90 minutes, the cells were washed three times in GVB\(^2\) and resuspended to \(8 \times 10^8/\text{mL}\). The number of C3b molecules per cell was determined using a radiolabeled monoclonal anti-C3 as previously described.\(^{23}\) The EC3b used in the experiments reported here bore \(33,000\) molecules C3b/cell.

**Phagocytosis assay.** Two hundred fifty microliters of 0.1 mol/L NaHCO\(_3\) or 0.1 mol/L NaHCO\(_3\), containing incremental concentrations of vitronectin or fibronectin were incubated in the chambers of eight-well Lab-Tek slides (Dynatech Laboratories, Alexandria, VA) at RT.\(^{24}\) After 2 hours, the slides were washed three times with PBS, and 250 \(\mu\)L monocyte suspension (\(5 \times 10^9/\text{mL}\)) was added to each chamber, and the slides were placed in a 5% CO\(_2\) incubator at 37°C. After 30 minutes, nonadherent cells were removed by washing the chambers three times with GVB\(^2\). Next, 250 \(\mu\)L EA or EC3b (\(8 \times 10^8/\text{mL}\)) was added to each chamber, and the slides were placed in a 5% CO\(_2\) incubator at 37°C. After 30 minutes, uningested EA or EC3b were lysed using hypotonic PBS (PBS diluted 1:3 with deionized water). After the supernate was aspirated, 250 \(\mu\)L 0.01 mol/L sodium phosphate, pH 7.4 containing 2% (vol/vol) glutaraldehyde, and 1% (wt/vol) sucrose were added to each well. After 15 minutes, the supernate was aspirated, and coverslips were mounted onto the slides. Using phase microscopy (Leitz Epivert, E. Leitz, Rockleigh, NJ), phagocytosis was quantitated. The number of monocytes ingesting one or more erythrocytes (percentage of phagocytosis) and the number of erythrocytes ingested per 100 monocytes (phagocytic index) were calculated after a minimum of 200 monocytes was counted.

**Effects of a combination of vitronectin and fibronectin on monocyte-mediated phagocytosis of EA.** These experiments were performed in the same fashion as those described above except that where indicated, a combination of vitronectin and fibronectin in 0.1 mol/L NaHCO\(_3\) was incubated in the appropriate wells.

**Effects of F(ab')\(_2\) anti-VN, and anti-FN on monocyte-mediated phagocytosis of EA.** Wells were incubated at RT with 250 \(\mu\)L 0.1 mol/L NaHCO\(_3\), or 250 \(\mu\)L 0.1 mol/L NaHCO\(_3\), containing either vitronectin (40 \(\mu\)g/mL) or fibronectin (40 \(\mu\)g/mL). After 2 hours, the wells were washed three times with PBS, and 250 \(\mu\)L GVB\(^2\) or GVB\(^2\) containing 600 \(\mu\)g/mL F(ab')\(_2\) fragment of nonimmune rabbit IgG, rabbit anti-VN or rabbit anti-FN were added to the appropriate wells. The slides were incubated at 37°C for 30 minutes and then washed three times in GVB\(^2\). The remainder of the experiment was performed as described above.

**Effects of fluid-phase IgG on monocyte-mediated phagocytosis.** Monocytes were allowed to adhere to wells that had been previously incubated with either 250 \(\mu\)L vitronectin (160 \(\mu\)g/mL), fibronectin (160 \(\mu\)g/mL), or 0.01 mol/L NaHCO\(_3\), as described above. Nonadherent cells were removed by washing, and 250 \(\mu\)L of either purified human IgG (10 \(\mu\)g/mL) or buffer was added to the appropriate wells. After 30 minutes at 37°C, 250 \(\mu\)L EA (1.6 \(\times 10^6\)) was added, and the incubation was continued for 30 minutes. Next, the wells were washed, and phagocytosis was quantitated as described above.

**Effects of vitronectin and fibronectin on monocyte-mediated phagocytosis of EC3b.** Wells were incubated with 250 \(\mu\)L of either vitronectin (160 \(\mu\)g/mL), fibronectin (160 \(\mu\)g/mL), or buffer for 2 hours at RT. The remainder of the experiment was performed as described above except that EC3b were substituted for EA. In experiments in which attachment was quantitated, the wells were washed twice with GVB\(^2\), but the cells were not exposed to hypotonic buffer.\(^{25}\) The attachment index is the number of EC3b bound per 100 monocytes.

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RESULTS

Analysis of vitronectin and fibronectin using SDS-PAGE and Western blotting. Intact vitronectin has an apparent mol wt of ~75 kd (Fig 1A, lane 2). Proteolysis of a 10-kd fragment from the COOH-terminal end of the native molecule creates the band whose electrophoretic mobility suggests a mol wt of ~65 kd. This 65-kd fragment contains the putative cell-attachment site (the RGD sequence is located in residues 45 through 47 from the NH2-terminus) as well as the glycosaminoglycan binding site.26 The function of the 10-kd cleavage fragment is unknown. Under reducing conditions, fibronectin has an apparent mol wt of 220 kd (Fig 1A, lane 3); however, its biologically active form is a disulphide-linked dimer (mol wt 440 kd). In the Coomassie-stained gels, we observed no contamination of either protein preparation.

To insure further that the vitronectin preparation did not contain fibronectin (and that the fibronectin preparation did not contain vitronectin), the two preparations were analyzed by Western blot. When the blots were developed using anti-vitronectin as the primary antibody, the lane containing the isolated vitronectin showed staining of both the 75 kd and 65-kd proteins (Fig 1B, lane 1), but the lane containing isolated fibronectin produced no reaction (Fig 1B, lane 2). In

Fig 1. A: SDS-PAGE of vitronectin and fibronectin preparations. A 6% to 12% gradient gel was run under reducing conditions and stained with Coomassie blue. Lane 1, mol wt markers; lane 2, vitronectin (5 µg); lane 3, fibronectin (5 µg). Vitronectin is a single chain polypeptide whose mol wt is ~75 kd. The band whose mol wt is ~65 kd is a proteolytic fragment derived from native vitronectin. B and C: Western blots using either rabbit anti-vitronectin (B) or anti-fibronectin (C) as the primary antibody. The blots were developed following incubation with peroxidase-conjugated goat anti-rabbit IgG. B: Lane 1, vitronectin (1 µg), lane 2, fibronectin (1 µg). C: Lane 1, vitronectin (1 µg), lane 2, fibronectin (1 µg). There was no evidence of contamination of either protein preparation, and the antibodies were specific.

Fig 2. Dose–response curve of (A) vitronectin (VN)- and (B) fibronectin (FN)-induced augmentation of phagocytosis of sheep EA by freshly explanted monocytes. Data points represent the mean ± SD (n = 3). In a dose-dependent fashion, vitronectin and fibronectin enhanced both the number of monocytes ingesting EA (percentage phagocytosis) and the number of EA ingested per monocyte (phagocytic index). C: Direct comparison of the effects of vitronectin (VN) and fibronectin (FN) on monocyte-mediated phagocytosis of EA. The wells were incubated with buffer alone or with buffer containing either 40 µg vitronectin or fibronectin. Results are shown as the mean ± SD (n = 3). On a weight basis, vitronectin and fibronectin augmented phagocytosis equally.
contrast, when anti-fibronectin was used as the first antibody, no reaction was observed in the lane containing the vitronectin (Fig 1C, lane 1), but staining was observed in the lane containing the isolated fibronectin (Fig 1C, lane 2). These results demonstrate both the purity of the protein preparations and the specificity of the antibodies used in these experiments.

Effect of vitronectin and fibronectin on ingestion of EA by monocytes. To determine if vitronectin modulates phagocytosis by monocytes of sheep erythrocytes bearing IgG, peripheral blood monocytes that had been isolated by elutriation were allowed to adhere to the wells of slides that had been previously incubated with buffer alone or with buffer containing incremental concentrations of vitronectin. After the cells were washed, EA were added to the wells, and phagocytosis was subsequently quantified. Vitronectin caused a dose-dependent increase in both the percentage of phagocytes and the phagocytic index, and the dose–response curve developed a plateau at 10 μg/well vitronectin (Fig 2A). On a weight basis, the effects of fibronectin on monocyte-mediated phagocytosis appear to be similar to those observed for vitronectin (Fig 2B). When maximum stimulatory concentrations of vitronectin and fibronectin were used, the percentage of phagocytosis was enhanced ~2.2 times and the phagocytic index increased ~3.2 times (Fig 2C). No ingestion of unopsonized sheep erythrocytes was observed under the conditions described above. Furthermore, no enhancement of phagocytosis was observed when either BSA or gelatin was substituted for vitronectin or fibronectin (data not shown). These experiments suggest that vitronectin and fibronectin induce an otherwise quiescent subpopulation of monocytes to phagocyte opsonized particles. In addition, the capacity of the monocytes to ingest multiple EA is also enhanced by these two proteins.

Effect of a combination of vitronectin and fibronectin on phagocytosis of EA by monocytes. To determine if vitronectin and fibronectin produced an additive effect on monocyte-mediated phagocytosis of EA, wells were incubated with 10 μg of either vitronectin or fibronectin. This amount was chosen because, for both proteins, it produces a near maximal enhancement of the phagocytic index. A second set of slides was incubated with buffer containing 10 μg of both vitronectin and fibronectin. A third set of slides was exposed to 20 μg of either vitronectin or fibronectin, an amount at which, individually, each protein produces its maximum stimulatory effect. If vitronectin and fibronectin were acting on different subpopulations of monocytes, or if the two proteins acted on independent stimulatory mechanisms, phagocytosis should be enhanced in an additive fashion when the two proteins are used in combination. This is not the case, however, inasmuch as the increase in phagocytosis induced by the combination of vitronectin and fibronectin is equivalent to that which occurs when the individual proteins are used in the same amount as the combination (Fig 3). These results are consistent with the concept that vitronectin and fibronectin act on the same population of monocytes and that the two proteins stimulate the same mechanism through which the enhanced phagocytosis is mediated.

Effects of antibodies on vitronectin and fibronectin-induced enhancement of phagocytosis of EA by monocytes. The specificity of the effects of vitronectin were investigated by determining the capacity of anti-vitronectin antibodies to inhibit the enhancement of phagocytosis induced by vitronectin. Slides were incubated with vitronectin or buffer containing no protein. After the slides were washed, the (Fab')2 fragment of anti-vitronectin, anti-fibronectin, or nonimmune IgG was added to appropriate chambers. The slides were once again washed and exposed sequentially to monocytes and EA as previously described. When anti-vitronectin (Fab')2 was added to chambers previously coated with vitronectin, the degree of phagocytosis was reduced to the level of that which occurred when no vitronectin was present (Fig 4). Nonimmune and anti-fibronectin (Fab')2 had no inhibitory activity. The effects of anti-vitronectin, anti-fibronectin, and preimmune IgG on the percentage of phagocytosis were identical to those observed for the phagocytic index (data not shown). These experiments demonstrate that the functional activity of vitronectin is inhibited by specific antibodies. Furthermore, since anti-fibronectin has no inhibitory activity, the effects on phagocytosis ascribed to vitronectin cannot be due to contamination of the vitronectin preparation with fibronectin. In a parallel set of experiments, slides were coated with fibronectin, and the capacity of the F(ab')2 fragments of anti-fibronectin, anti-vitronectin, and nonimmune IgG to inhibit fibronectin-induced enhancement of monocyte-mediated phagocytosis of EA was assessed. The results of these experiments were analogous to those described above, in that anti-fibronectin

![Figure 3](image-url)
reduced fibronectin-stimulated phagocytosis to the level of that which occurred when no fibronectin was present, and anti-vitronectin and nonimmune IgG had no effect (data not shown).

Effects of fluid-phase IgG on vitronectin and fibronectin-mediated enhancement of phagocytosis of EA by monocytes. Phagocytosis of EA by monocytes is mediated by the FcR. To determine if vitronectin and fibronectin can modulate phagocytosis in the presence of fluid-phase IgG, monocytes, which were adherent to slides coated with vitronectin or fibronectin, were incubated with either buffer alone or buffer containing purified IgG (the concentration of IgG used in this experiment was in excess of that required to saturate the FcR). Next, without washing, EA were added to the wells, and the slides were incubated for at 37°C. After 30 minutes, the wells were washed. Phagocytosis was subsequently quantified as described above. Fluid-phase IgG markedly inhibited phagocytosis of EA by monocytes incubated with either vitronectin or fibronectin (Fig 5). These experiments demonstrate that unoccupied FcR are necessary for the two proteins to exert their effects.

Effects of vitronectin and fibronectin on rosetting and phagocytosis of EC3b by monocytes. To determine if vitronectin and fibronectin influence the functional activity of monocyte receptors for C3b, sheep erythrocytes bearing ~33,000 molecules of C3b per cell were created using isolated components of the alternative pathway of complement. The attachment index of EC3b to monocytes that were adherent to slides that had been incubated with buffer containing either vitronectin or fibronectin was ~ten times greater than that observed for monocytes adherent to slides that had been incubated with buffer alone (Fig 6). In contrast, ingestion of EC3b by unstimulated monocytes was minimal, and vitronectin and fibronectin enhanced phagocytosis only modestly (Fig 6). These experiments demonstrate that both vitronectin and fibronectin modulate the functional activity of monocyte receptors for C3b. Despite the marked enhancement of attachment by both vitronectin and fibronectin, the capacity of freshly isolated peripheral blood monocytes to phagocytize EC3b appears to be extremely limited.

DISCUSSION

The studies we report here demonstrate that vitronectin interacts directly with monocytes, thereby augmenting the functional activity of both the FcR and the receptor(s) for C3b. We (in this report) and other authors have shown that fibronectin has a similar stimulatory effect on monocyte function. It was therefore essential to ensure that the vitronectin preparation used in these experiments did not contain fibronectin. The Coomassie-stained gel of the vitronectin preparation (Fig 1A, lane 2) showed only the 75-kd and 65-kd forms of vitronectin, and the Western blot of this same
preparation developed using anti-fibronectin (Fig IC, lane 1) revealed no staining. Furthermore, the F(ab')2 fragment of anti-vitronectin IgG completely inhibited the greater phagocytosis of EA induced by vitronectin, whereas anti-fibronectin F(ab')2 IgG had no effect (Fig 4). Together, these results demonstrate that the enhancement of monocyte function attributed to vitronectin is not due to the presence of fibronectin in the vitronectin preparation. Furthermore, the inhibition of vitronectin activity by antibody implies a specific receptor–ligand interaction involving the monocyte and vitronectin.

A specific receptor for vitronectin has been identified. It is a heterodimer consisting of a 125-kd α chain and a 115-kd β chain. On the basis of amino acid homology, and similarities of size and subunit structure, the vitronectin receptor belongs to a family of adhesive protein receptors that includes platelet GP IIb/IIIa, the fibronectin receptor, CR3 (the receptor for complement C3b, also known as Mac1 and Mo 1), LFA-1, and GP 150/95. The vitronectin receptor is particularly closely related to GP IIb/IIIa, and antibodies that recognize epitopes expressed by the β subunit of the vitronectin receptor, crossreact with GP IIIa. Because of this immunologic crossreactivity, and their similarity when analyzed by SDS-PAGE, in some cases, the protein identified as GP IIb/IIIa in cells other than platelets may be the vitronectin receptor. Indeed, a preliminary report by Charo et al have suggested that this is the case for endothelial cells. By analogy, the GP IIb/IIIa-like protein reported to be present on monocytes may be the vitronectin receptor.

Fibronectin binds to GP IIb/IIIa when platelets are stimulated by thrombin, and both fibronectin and vitronectin have been reported to bind to isolated GP IIb/IIIa. Thus, in some instances, the binding of vitronectin and fibronectin to cells may not be mediated by their specific receptor but rather by a discrete membrane constituent with a recognition site for both proteins. Fibrinogen and von Willebrand factor also bind to platelet GP IIb/IIIa, and for each of these proteins, a portion of the molecule containing the RGD sequence appears to be involved in the binding interaction.

Saturable, specific binding of fibronectin to monocytes has been reported, but the monocyte receptor for fibronectin has not been isolated. Neither the characteristics of binding of vitronectin to monocytes nor identification of the binding site has been determined. Thus, whether vitronectin and fibronectin bind to their specific receptors on monocytes or to a common receptor which recognizes these, and perhaps other, cytoadhesive proteins containing RGD remains to be elucidated. The results of the experiments we report do not distinguish between these two possibilities.

Vitronectin and fibronectin cause a similar dose-dependent increase in both the percentage of phagocytosis and the phagocytic index (Fig 2A through C), and the dose–response curves develop a plateau when ~10 μg of either protein is added (Fig 2A and B). Obviously, the percentage of phagocytosis cannot exceed 100; however, that the dose–response curve for the phagocytic index develops a plateau suggests that the capacity of the monocyte to respond to the stimulus is finite. At least two explanations for this observation seem plausible. First, receptor sites for vitronectin and fibronectin may become saturated when ~10 μg of protein are added to the wells. Thus, when the receptors are fully occupied, the stimulatory signal is maximal. Second, the capacity of the FcR to respond to the stimulatory signal generated by interaction of vitronectin and fibronectin with the monocyte may be limited. According to this hypothesis, maximum enhancement of phagocytosis would not require that receptor sites for vitronectin and fibronectin be fully occupied.

We have observed that both vitronectin and fibronectin markedly augmented the attachment of EC3b to monocytes; however, these proteins caused minimal enhancement of phagocytosis of EC3b (Fig 6). The results of these experiments are in agreement with those of Wright et al but differ from those of Pommier et al, who reported that fibronectin enhances phagocytosis of EC3b by freshly explanted monocytes. The explanation for these apparent discrepancies is unclear, but differences in the methods of preparation of the monocytes or of the EC3b may be involved. Nonetheless, clearly both vitronectin and fibronectin modulate the functional activity of the monocyte receptors for C3b (Fig 6).

Monocytes bear two types of receptors, CR1 (the C3b/C4b receptor) and CR3 (the iC3b receptor) which bind C3b, and in the case of cultured monocytes, both receptors can be induced by PMA (phorbol myristate acetate), fibronectin, laminin, and serum amyloid P to mediate phagocytosis of opsonized particles. By analogy, vitronectin may also stimulate both CR1 and CR3.

The mechanism by which vitronectin and fibronectin enhance the functional activity of monocyte receptors for C3b and IgG has not been elucidated; however, in the case of
fibronectin, a quantitative increase in receptor number does not appear to be involved. Recently, Changelian and Fea-
ron demonstrated that PMA induces phosphorylation of monocyte CR1 but not CR3 or FcR. Thus, whereas phos-
phorylation appears to be involved in modulation of CR1 activity, other mechanisms may regulate the activity of FcR 
and CR3. It will be of interest to determine if vitronectin or fibronectin can induce receptor phosphorylation. That pro-
teins (laminin and Clq which apparently do not contain the RGD sequence can induce effects similar to those 
observed for vitronectin and fibronectin suggests that receptors other than those which recognize RGD can initiate the 
same sequence of events that lead to augmentation of FcR, CR1, and CR3 activity. Alternatively, or in addition, more 
than one pathway for stimulation may exist.

In the process of migration to extravascular sites of inflammation, monocytes encounter extracellular matrix 
proteins. Thus, stimulation by these proteins of monocyte receptors that mediate attachment and ingestion of oso-
nized particles may be a critical event in initiation and modulation of the phagocytic component of cellular immu-
ity. In addition, fibronectin is synthesized by monocytes. Whether monocytes also produce vitronectin constitutively 
remains to be determined. Recently, Chhatwal et al. have reported specific binding of vitronectin to streptococci, 
Staphylococcus aureus, and Escherichia coli, suggesting the possibility that under some circumstances, vitronectin may 
directly augment phagocytosis of opsonized bacteria by monocytes. Because of its regulatory activity in cell–
substrate and cell–cell interactions, the complement system, the coagulation systems and monocyte function, vitronectin 
appears to be an important constituent of the processes of inflammation and repair.

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