IDENTIFICATION OF THE RAJI CELL MEMBRANE-DERIVED Clq INHIBITOR AS A RECEPTOR FOR HUMAN Clq

Purification and Immunochernical Characterization

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Clq is a 410,000 mol wt glycoprotein that circulates in plasma at a concentration of 65–70 μg/ml and constitutes a subunit of the first component of complement, C1 (1). In plasma, C1 circulates as a calcium ion-dependent pentamolecular complex consisting of one molecule of Clq, two molecules of Clr, and two molecules of Cls, to give a structural formula, Clq₁Clr₂Cls₂ (2). During activation of the classical pathway of complement, Clq, within the C1 macromolecule, functions as the recognition unit (3) by virtue of its ability to recognize and bind to the Cn2 domain of IgG (4, 5) and Cn3 or Cn4 domains of IgM (6, 7). It is a collagen-like molecule (1) with six flower-like globular heads that constitute the binding sites for Ig (4). Each globular head contains the carboxyl-terminal ends of three similar but distinct polypeptide chains (A, B, C) of ~20,000–22,000 mol wt that occur six times in the molecule, forming six structural and functional subunits (3, 8, 9). The amino-terminal regions of each chain are collagen-like and associate to form a helical configuration that represents the binding sites for Cl₁Clr₂Cls₂ (9–10).

In addition to being a recognition unit of the classical pathway of complement, Clq functions as a ligand for a number of cellular receptors (recently reviewed in 11) such as B lymphocytes (12, 13), lymphoblastoid cells (14, 15), null cells, monocytes, polymorphonuclear leukocytes (16, 17), fibroblasts (18), and platelets (19, 20); and the binding of Clq to certain types of cells elicits some biological functions. For instance, we have shown previously (15) that lymphocytes or lymphoblastoid cells such as Raji cells are capable of lysing Clq-coated, chromium-labeled chicken erythrocyte (Ec) target cells. That the pre-killing, effector cell-target cell contact is mediated by the effector cell Clq receptor (ClqR) was

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Abbreviations used in this paper: ClqR, Clq receptor; CNBr, cyanogen bromide; DTT, dithiothreitol; EA, antibody-sensitized sheep erythrocytes; EACA, epsilon-amino-caproic acid; Ec, chicken erythrocytes; E₅₀, human erythrocytes; GVB, veronal-buffered saline containing 0.15 mM CaCl₂, 0.5 mM MgCl₂, and 0.1% gelatin; HBSS, Hanks' balanced salt solution; NHS, normal human serum; NP-40, Nonidet P-40; PBS, phosphate-buffered saline; PEG, polyethylene glycol; PMSF, phenylmethylsulfonyl fluoride; SDS–PAGE, sodium dodecyl sulfate–polyacrylamide gel electrophoresis.
demonstrated by pretreatment of the target cells with F(ab')₂ anti-C1q, which abrogated the cytotoxic effect (15). Furthermore, monomeric C1q was reported to inhibit the collagen-dependent aggregation of platelets (19, 20) and the release of serotonin (21). The importance of C1qR was not fully appreciated, partly because, in normal serum, C1q occurs as a subunit of the C1 complex. The amount of available free C1q was therefore thought to be very small. However, C1qR assumed new significance after it was observed that CT-INa, the plasma inhibitor of activated C1, rapidly dissociates the activated C1r and C1s subunits from the C1 complex (22), thus leaving C1q bound to immune complexes.

In previous reports (23, 24), it was shown that a substance could be solubilized from membranes of lymphocytes or lymphoblastoid cells (Raji) that possesses the property of binding and precipitating free C1q, and hence was described as a C1q precipitin (25) or membrane-derived C1q inhibitor (M-C1qINH²) (24). In the present study, evidence is presented demonstrating that this membrane-derived inhibitor constitutes the cellular receptor for C1q.

Materials and Methods

Materials. The following materials were purchased: Nonidet P-40 (NP-40), lactoperoxidase, glutaraldehyde (Sigma Chemical Co., St. Louis, MO); Na¹²⁵I and Bolton-Hunter reagent (New England Nuclear, Boston, MA); Ficoll-Hypaque (Pharmacia Fine Chemical, Piscataway, NJ), cyanogen bromide (CNBr) (Eastman Kodak Co., Rochester, NY), N,N-dimethylformamide (Aldrich Chemical Co., Milwaukee, WI), polyethylene glycol (PEG) (PEG 6000; Fisher Scientific Co., Pittsburgh, PA), and RPMI and other tissue culture reagents (Gibco Laboratories, Grand Island, NY).

Purified Proteins. Highly purified C1q was isolated according to a method previously described (25) and the protein concentration determined either by the method of Lowry et al. (26) or by measuring the optical density at 280 nM and using an extinction coefficient E₁% of 6.8. The homogeneity of a representative preparation of C1q used in these studies is shown in Fig. 1.

Radioiodination of Proteins. All radiolabeled proteins were labeled with ¹²⁵I by the Bolton-Hunter method as described (27) unless otherwise specified. Typically, 100 µg of isolated protein in 0.1 M sodium borate buffer (pH 8.5) were added to 100 µCi of Bolton-
Hunter reagent and allowed to react for 30 min at 4°C. The reaction mixture was then dialyzed against phosphate-buffered saline (PBS), pH 7.0, at 4°C until the dialysate was free of $^{125}$I.

**Preparation of Clq-Sepharose 4B.** Highly purified Clq was coupled to Sepharose 4B according to the method described by March et al. (28). Briefly, 50 ml of packed Sepharose 4B was washed extensively with deionized water and resuspended in 50 ml of 5 mM potassium phosphate tribasic buffer, pH 12.5 and stirred in an ice bath kept in a fume hood for 15 min. Then 7 g of CNBr dissolved in 3.5 ml of N,N-dimethylformamide were quickly added and the mixture was stirred for 5 min. The Sepharose beads were then washed in a Buchner filter funnel in the fume hood with 2 liters of water followed by 2 liters of coupling buffer consisting of 8 g NaHCO$_3$, 29.2 g NaCl/l, pH 9.0. The CNBr-activated Sepharose was mixed in a wide-mouth, 250-ml plastic bottle with 50 ml of human Clq (2 mg/ml) that had been dialyzed against coupling buffer, and the mixture was left for 16 h at 4°C with continuous stirring, after which it was placed in a Buchner funnel and evacuated to dryness. The amount of protein coupled to the Sepharose was determined by assaying the protein content in the filtrate. The Clq-Sepharose was then washed with 1 liter of PBS, pH 7.0 and resuspended in 50 ml of 1 M glycine, pH 8.0 for 2 h at 22°C to block the unreacted sites on the Sepharose beads. The slurry was washed by filtration with 1 liter of 5 mM sodium phosphate buffer, pH 7.5, containing 0.5 mM EDTA, 150 mM NaCl, and 0.02% NaN$_3$, and poured into a 1.5 x 20 cm column. Before each use, the Clq-Sepharose column was tested for its activity by taking 0.5 ml of packed beads and incubating them with 0.2 ml of monospecific, polyclonal antiserum to Clq for 1 h at 4°C. After incubation the mixture was centrifuged (500 rpm, 5 min) and the remaining anti-Clq activity of the supernatant tested by Ouchterlony analysis, as shown in Fig. 2.

**Lymphoblastoid Cell Line.** The cell line, Raji, used in this study was taken from a continuous culture line propagated in RPMI containing 10% fetal calf serum and 1% antibiotic-antimycotic mixture and was originally derived from a patient with Burkitt’s lymphoma (29, 30).

**Purification of Clq Receptor.** The purification of ClqR was essentially the same as that described earlier (24) with only minor modifications. Briefly, 3 x 10$^9$ Raji cells were washed three times and resuspended in 100 ml of 5 mM sodium phosphate buffer, pH 7.5, containing 0.5 mM EDTA, 150 mM NaCl, 10 mM EACA, and 0.5 mM phenylmethylsulfonyl fluoride (PMSF). Cell membranes were prepared by freeze-thawing (five times) at -80°C and centrifugation for 1 h at 30,000 g at 4°C. The pellet membranes were then solubilized by suspension in 50 ml of the above buffer containing 1% NP-40 and stirred for 20 h at 4°C. The solubilized membrane proteins were freed from insoluble material by centrifugation at 30,000 g for 60 min at 0°C and the total protein concentration was determined to be 30 mg. After dialysis against 5 mM NaPO$_4$, buffer, pH 7.5, containing 0.5 mM EDTA, 20 mM NaCl, 10 mM EACA, 0.5 mM PMSF, and 0.1% NP-40, 10 mg of the dissolved membrane solution was applied to a 1.5 x 20 cm Clq-Sepharose 4B column that had been equilibrated with the same buffer. The column was then washed with 600 ml of the starting buffer and the specifically bound proteins eluted with a linear NaCl concentration gradient. Fractions containing Clq-binding activity were deter-

![Figure 2. Depletion of anti-Clq activity on a Clq-Sepharose 4B column. A sample of a monospecific, polyvalent antibody to Clq was incubated with Clq-coated Sepharose. Depletion of anti-Clq was another means of showing that the Sepharose beads were coated with the Clq offered.](image-url)
mined by single or double immunodiffusion techniques in a 0.8% agarose (sodium phosphate buffer, pH 7.2) containing 1.5% PEG 6000, using highly purified human Clq as described earlier (24, 31), and concentrated on an Amicon pressure filtration device with a Diaflow UM-10 ultrafiltration membrane (Amicon Corp., Danvers, MA). When the ClqR was used in a hemolytic assay, the detergent concentration was always reduced to ~0.01% by passage through a column of QAE-50 Sephadex as described (24).

**Sodium Dodecyl Sulfate-Polyacrylamide Gel Electrophoresis (SDS-PAGE) Analysis of ClqR.** After radiolabeling with Bolton-Hunter reagent (27), the isolated ClqR was reduced and alkylated by boiling for 5 min in the presence of 0.1 M dithiothreitol (DTT) and 0.2 M iodoacetamide and was analyzed by application on a 1.5-mm thick, 5–10% acrylamide gradient containing slab gels, using the method of Laemmli (32). After electrophoresis, the gel was stained with Coomassie Blue, vacuum-dried, and analyzed by autoradiography.

**Ultracentrifugation Analyses.** Ultracentrifugation analysis of isolated ClqR was determined on a 5–40% sucrose-containing linear gradient in 5 mM NaPO₄ buffer containing 90 mM NaCl, 10 mM EACA, 0.5 mM EDTA, 0.5 mM PMSF, and 0.1% NP-40, pH 7.4. Centrifugation was carried out in a Beckman model L5-75B ultracentrifuge (Beckman Instruments, Inc., Fullerton, CA) using an SW65 rotor for 20 h at 50,000 rpm. Clq (11S), C3 (9.5S), albumin (4.6S), and cytochrome c (1.7S) were used as markers.

In another set of experiments, an equilibrium density gradient ultracentrifugation was run in the following manner. First, the isolated ClqR was dialyzed overnight at 4°C against distilled water and then lyophilized. The dried residue was then dissolved in 8 ml of a solution comprised of 4 M guanidinium chloride, 0.05 M sodium acetate, pH 5.8, N-ethyl malimide, 0.1 M EDTA, 0.1 M EACA, and 0.005 M benzamidine, that contained cesium chloride to a density of 1.5 g/ml. The solution was centrifuged at 12°C for 72 h at 100,000 rpm in a Beckman ultracentrifuge using a swing-out rotor (SW60). The tubes were then frozen in liquid nitrogen and cut into two fractions: the bottom 2/5 and the bottom 3/5 by volume. The fractions were then dialyzed against 0.2 M sodium acetate, pH 5.8 and then against distilled water at 4°C. Finally, the material was lyophilized and then dissolved in 1.0 ml of distilled water. Protein and uronate were determined on an autoanalyzer (Techicon Instruments Corp., Tarrytown, NY).

**Amino Acid Analysis.** Amino acid analysis was performed with an amino acid analyzer (model 121M; Beckman Instruments, Spinco Division, Palo Alto, CA) equipped with an automatic sample injector and a model System AA automatic digital integrator. The sample was hydrolyzed in 6 N HCl for 20 h at 110°C in evacuated and sealed Pyrex tubes. ~25 nmol of hydrolyzed protein were applied to each column and the amino acid concentration was determined by comparison with a standard mixture of amino acids (100 nmol/ml).

**Effect of Chondroitinase ABC on ClqR.** To determine the effect of chondroitinase ABC, 0.1 µg purified ¹²⁵I-C1qR was dissolved in 0.1 µl of Tris-HCl, pH 8.0, and incubated with buffer alone or with 0.1 U of enzyme as described previously (31) for 12 h at 37°C. Then the sample was dialyzed against buffer containing 0.14 M Na₂SO₄, 0.01 cacodylic acid, and 0.1% NP-40. The chondroitinase-digested sample and the control sample were sequentially applied to a column of Sepharose CL-6B (0.5 × 120 cm; matrix, 108 cm) equilibrated with same buffer together with 250 µg of bovine nasal cartilage proteoglycan A1D1 (V₅ marker, ~2.2 × 10⁶ mol wt) and 20 µg glucuronolactone (V₇ marker, ~176 mol wt) and eluted with the same buffer at a flow rate of 5 ml/h. Fractions were analyzed by Ouchterlony using isolated Clq and by the carbazole method of uronic acid determination (33).

**Inhibition of EClq Rosettes by ClqR or Monoclonal Antibody to ClqR.** The ability of ClqR to inhibit Clq-dependent rosette formation was determined by a previously described rosette assay (34, 35) and consists of the following steps. First, human erythrocytes (Eₐ) were treated with 100 vol of 2% glutaraldehyde in 0.15 M PBS, pH 7.4, at 4°C for 16 h. The cells were washed with Hanks' balanced salt solution (HBSS) and further incubated with 10 vol of HBSS containing 10 mg/ml L-lysine for 30 min at 37°C, after which the cells were washed and resuspended in HBSS at 1 × 10⁹/ml. Then 5 × 10⁶ cells
in 1 ml HBSS were incubated with 200 μg Clq and a tracer amount (1 μg) of 125I-Clq (8 × 10^5 cpm/μg). The excess unbound Clq was removed by centrifugation in HBSS. Rosette formation was then assayed by incubating 1.5 × 10^7 Eα Clq with 5 × 10^6 Raji cells in a total volume of 0.4 ml HBSS for 5 min at 37°C, centrifuging for 5 min at 600 rpm, and further incubation for 60 min at 4°C. To determine the inhibitory effect of isolated ClqR, the Raji cells were either pretreated with 5 μg/ml F(ab')2 or the reaction mixture was incubated in the presence of 5 μg ClqR. The percent rosettes formed was determined by counting at least 100 lymphocytes in a microscope (Microstar; American Optical Scientific Instruments, Buffalo, NY).

Clq-dependent Cytotoxicity Assay. 51Chromium-labeled, Clq-coated chicken erythrocyte target cells (51Cr-Eα) were prepared as described earlier (15). The inhibitory effect of ClqR was tested by preincubating 10 μg ClqR with 8 × 10^4 51Cr-Eα and leaving the excess unbound ClqR in the reaction mixture, which contained, in addition, 2 × 10^8 Raji cells in a total volume of 0.4 ml of RPMI containing 0.4 human serum albumin, 2 mM L-glutamine, and 1% antibiotic-antimycotic mixture (penicillin 10,000 U/ml, fungizone 25 μg/ml, streptomycin 10,000 mcg/ml). Incubation was carried out at 37°C in a CO2 incubator for 20 h. After incubation, the reaction mixture was centrifuged for 10 min at 1,000 rpm, the radioactivity of both pellet and supernatant determined, and cell damage expressed as the percentage of the total radioactivity released from the cell into the supernatant.

Effect of Isolated ClqR on Clq Hemolytic Function. There is evidence in the literature indicating that the Clq receptor reacts with the collagen-like region of the molecule (16, 24). Since this region also constitutes the site to which Clr and Cls bind, an experiment was performed to see if the isolated molecule could inhibit the hemolytic activity of Cl in serum. This was determined by incubating 5 μg/ml of purified ClqR (which had been repurified on a QAE-Sephadex column to reduce the detergent concentration) with or without 50 ng of Clq for 60 min at 37°C, followed by an additional 60 min incubation in the presence of 10 μl of Clq-depleted serum (containing 20 mM CaCl2) and antibody-sensitized sheep erythrocytes (EA) (5 × 10^6/ml) in a total volume of 0.5 ml GVB (veronal-buffered saline containing 0.15 mM CaCl2, 0.5 mM MgCl2, and 0.1% gelatin) (24). After incubation, the cells were centrifuged and the amount of hemoglobin released into the supernatant was determined spectrophotometrically at 700 nm. The inhibitory effect of the isolated substance was expressed as the percent inhibition of Clq hemolytic activity.

Results

Purification of ClqR by Affinity Chromatography. When a total of 10 mg of unlabeled and tracer amount (1 × 10^6 cpm/μg) of surface-labeled, NP-40-solubilized Raji cell membranes were chromatographed on a Clq-Sepharose 4B column and bound proteins eluted with a linear NaCl concentration gradient, two discrete, Clq-reactive peaks eluted at approximately 22 and 30 mmho/cm, respectively (Fig. 3). This seems to suggest that Raji cells possess two species of receptors with different affinities or charge heterogeneity. The two peaks were then separately pooled, concentrated, and designated arbitrarily as Clq receptor I and II (ClqRI and -II). From the tracer amount of radiolabeled protein incorporated, it was determined that the two Clq-reactive proteins represent ~7% of the total labeled Raji cell membrane proteins.

Immunodiffusion Analysis of Isolated ClqR. Equal concentrations of the pooled and concentrated peaks, ClqRI and ClqRII, were tested for their ability to bind and precipitate Clq using double (Fig. 4A) and single (Fig. 4B) immunodiffusion techniques. Both pools were found to be reactive, although the precipitation ring obtained by ClqRII (Fig. 4B) was apparently stronger than that for ClqRI, probably due to the disparity in concentration, since ClqRII was found to
contain at least two other protein bands (see below). Furthermore, C1qR was found to react with normal human serum (NHS) that contains EDTA but not NHS alone, indicating that under physiologic conditions where C1q is in complex with C1r2 and C1s2, the receptor does not bind to C1q in NHS.

**SDS-PAGE Analysis of C1qR.** Both C1qRI and C1qRII were radiolabeled with $^{125}$I and analyzed on a 10% SDS gels. As shown in Fig. 5, both C1qR preparations contained a major band (80–90 kD) that, under reducing conditions, resulted in a single, 60–70 kD band. However, while C1qRII was relatively homogeneous, C1qRI was found to contain at least two distinctly visible bands that together represented ~50% of the preparation.

It is also of interest that the C1qR molecule has a much more pronounced $^{125}$I band upon reduction than without reduction, indicating that the protein moiety might exist as a polymeric structure of disulfide-bonded 70,000 mol wt chains. Furthermore, some visible bands were observed at the top of the gel, and two or three protein bands were visible that did not label with $^{125}$I.

**Ultracentrifugation Analysis.** Sucrose density ultracentrifugation analysis revealed that the C1qR sediments at ~4.2 S; the results of one such experiment is shown in Fig. 6. In addition, equilibrium density gradient ultracentrifugation showed that the isolated receptor could be separated into a protein-rich, low density fraction and a carbohydrate-rich, high density fraction (Table I). The large hydrodynamic size, coupled with the high buoyant density and uronic acid content, suggests that a proteoglycan is a constituent of the complex.

**Amino Acid Analysis.** The results of amino acid analysis data are represented in Table II. One of the striking features is that C1qR is rich in glycine, with glutamic acid and aspartic acid following closely behind, which explains its acidic
FIGURE 4. Immunodiffusion analyses of ClqR. Isolated receptor pools were analyzed by double (A) and single (B) immunodiffusion techniques. Both plates contained 0.8% agarose in PBS, pH 7.4, 1.5% PEG, and 0.02% NaN₃. The agarose in plate B contained, in addition, 25 μg/ml of purified Clq. ClqRII precipitated Clq in NHS containing EDTA (NHS-E) but not in NHS.

The hexosamine ratio, or the ratio of galactosamine to glucosamine, was found to be 3.2. Furthermore, the uronic acid content of a typical ClqR preparation was found to be 23%, while galactosamine content was 21%.

Digestion of ClqR with Chondroitinase ABC. Previous studies postulated that the plasma-derived Clq inhibitor, which was identified as a chondroitin 4-sulfate proteoglycan (31), and the lymphocyte membrane-derived Clq inhibitor (ClqR), could be similar or identical. To assess this issue, an experiment was designed in which the ClqR was incubated with either buffer or chondroitinase ABC, as described in Materials and Methods. Both materials were then applied to a CL-6B column (0.5 x 120 cm; matrix height, 105 cm). After elution, it was found that the treated and untreated ClqR chromatographed in the same region, with a Kᵥ of 0.45 (Fig. 7), indicating that ClqR is not digestable with chondroitinase. Furthermore, chondroitinase-digested ClqR did not lose its ability to precipitate Clq as assessed by a double radial immunodiffusion analysis, as described.

Inhibition of Clq-dependent Biological Functions by ClqR. The ability of isolated ClqR to inhibit Clq-dependent rosette formation was tested by preincubating glutaraldehyde-treated, Clq-coated E₆ with or without 5 μg/ml of the receptor and then with either peripheral blood lymphocytes that had been purified by centrifugation on Ficoll-Hypaque (36) or Raji cells for 60 min at 4°C. As shown in Table III, 5 μg/ml of ClqR was able to inhibit rosette formation. Furthermore,
FIGURE 5. SDS-PAGE gel analysis of Clq-Sepharose pools. The pooled fractions in Fig. 3 were concentrated and radiolabeled before further purification. The specific activity was $7.7 \times 10^3$ and $5.1 \times 10^3$ cpm/µg for pool I (ClqRI) and pool II (ClqRII), respectively. ~5 $\times 10^4$ cpm (~7 µg) of each sample was applied to a Laemmli slab gel (10%) in the absence (1 and 3) or presence (2 and 4) of 0.1 M DTT. After electrophoresis the gel was stained with Coomassie Blue, vacuum-dried, and exposed in a Dupont Cronex cassette with Lightning Plus screens for 24 h at $-80^\circ$C before autoradiographic analysis.

both the Clq-dependent cellular cytotoxicity (Table IV) and hemolytic functions (Table V) were found to be inhibited by ClqR.

Discussion

In previous reports (23, 24) we isolated a lymphocyte membrane-associated Clq precipitin (23) or M-C1q inhibitor (24) and demonstrated that it was capable of inhibiting some of the Clq-dependent biological functions. The questions that arose from these studies were: (a) What is the exact chemical nature of the membrane-derived Clq inhibitor? (b) What is its relationship to the plasma Clq inhibitor? and (c) Is the Clq inhibitor identical to the Clq receptor on lymphocytes? To answer these questions and further characterize the chemical, as well as the functional nature, the membrane-associated inhibitor was isolated to homogeneity using a Clq-Sepharose 4B affinity column as described earlier (23). The present results clearly demonstrate that the isolated Clq inhibitor constitutes the cellular receptor for Clq and that it may exist as two distinct populations of receptors possessing different affinities for the Clq molecule.
Distribution of Isolated ClqR in Cesium Chloride Density Gradient Ultracentrifugation

<table>
<thead>
<tr>
<th>Fractions*</th>
<th>Density</th>
<th>Protein</th>
<th>Uronic acid</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bottom</td>
<td>1.55</td>
<td>24</td>
<td>6.25</td>
</tr>
<tr>
<td>Top</td>
<td>1.45</td>
<td>100</td>
<td>3.50</td>
</tr>
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</table>

* A lyophylized preparation of ClqR that had been dissolved in 4 M guanidinum chloride, containing 0.05 M sodium acetate, pH 5.8, N-acetyl maleimide, 0.1 M EDTA, 0.1 M amino-caproic acid, 0.005 M benzamidine, and 1.5 g/ml cesium chloride, was centrifuged at 12°C for 72 h. The fractions were collected by freezing the tubes and cutting. Protein and uronate were determined on a Technicon autoanalyzer.

This conclusion is derived from the observations that when the detergent-solubilized membrane proteins were applied to the Clq-Sepharose 4B column, washed exhaustively, and the adsorbed materials eluted, two discrete peaks eluting at different ionic strengths (22 and 30 mmho/cm, respectively) were obtained. Both species had similar properties since both were capable of binding...
TABLE II
Amino Acid Composition of ClqR

<table>
<thead>
<tr>
<th>Amino acid</th>
<th>Total nanomoles</th>
<th>Res/1,000</th>
<th>Total micrograms</th>
</tr>
</thead>
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<tr>
<td>Aspartic acid</td>
<td>9.1</td>
<td>93.8</td>
<td>1.2</td>
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<tr>
<td>Threonine</td>
<td>4.9</td>
<td>50.5</td>
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<td>Serine</td>
<td>8.0</td>
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<td>0.8</td>
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<tr>
<td>Glutamic acid</td>
<td>10.0</td>
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<td>1.5</td>
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<tr>
<td>Proline</td>
<td>7.9</td>
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<td>Glycine</td>
<td>18.5</td>
<td>190.7</td>
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</tr>
<tr>
<td>Alanine</td>
<td>7.3</td>
<td>75.5</td>
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<td>Cysteine</td>
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<tr>
<td>Isoleucine</td>
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<td>Tyrosine</td>
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<td>Galactosamine</td>
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<td>75.3</td>
<td>1.3</td>
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The percent total sample on the column is 67.28; total nanomoles of amino acids, 97; total micrograms of protein, 11.6. Hexosamine ratio: glucosamine/galactosamine, 0.3; galactosamine/glucosamine, 3.2.

and precipitating free Clq, although the concentration of ClqRI (after further purification) required to precipitate the same amount of Clq was one-half that of pool II. However, the conclusion that two distinct cell receptor populations might exist should await binding studies to determine their affinity constants. Clq possesses two binding sites for certain types of mucopolysaccharides such as low molecular weight heparin (37); the high affinity-binding site was shown to be the collagenous region of the molecule. That the Clq inhibitor is a cellular receptor for Clq (ClqR) is inferred from the following lines of evidences. (a) When the isolated material or ClqR was preincubated with Clq-bearing, glutaraldehyde-treated E₅, no rosette formation was obtained upon subsequent incubation with lymphocytes or Raji cells. (b) Clq-coated, ⁵¹Cr-labeled chicken erythrocyte target cells were prevented from lysis by Raji cells when the target cells were first preincubated with the ClqR. That this complement-mediated cellular cytotoxicity (CDCC) is mediated by the effector cell–Clq receptor has been previously documented (15). (c) ClqR binds to free Clq and this ClqR-bound Clq was unable to reassemble and form a hemolytically active Cl in the presence of Clq-depleted serum and 20 mM Ca++. (d) In addition, other experiments have shown that binding of ¹²⁵I-Clq to Raji cells was abrogated in the presence of ClqR, indicating that the isolated receptor could compete for
the binding of Clq. Furthermore, murine F(ab')2 monoclonal antibody to ClqR was found to inhibit $^{125}$I-Clq binding to Raji cells.

The Clq molecule is collagen-like with six globular heads that are the binding sites for Ig. The collagenous tail of the molecule is considered to be the site where Clr and Cls bind in plasma. The collagenous region of the molecule constitutes the site through which Clq binds to receptors (14-17). Our finding that ClqR was unable to precipitate Clq in serum seems to confirm these findings.

The results obtained from equilibrium gradient ultracentrifugation indicate

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**TABLE III**

<table>
<thead>
<tr>
<th>Reaction mixtures</th>
<th>Percent rosettes*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Raji + EC1q</td>
<td>81</td>
</tr>
<tr>
<td>Raji + (EC1q + ClqR)</td>
<td>7</td>
</tr>
<tr>
<td>PBL + EC1q</td>
<td>39</td>
</tr>
<tr>
<td>PBL + (EC1q + ClqR)</td>
<td>10</td>
</tr>
</tbody>
</table>

* Rosettes were formed by incubating 0.2 ml peripheral blood lymphocytes (PBL) or Raji cells (2.5 X $10^9$/ml) with 1.5 X $10^9$ Clq-coated (15 μg) glutaraldehyde-treated human erythrocytes (EC1q) in a total volume of 0.4 ml HBSS for 5 min at 37°C, centrifuging 5 min at 600 rpm, and further incubating for 60 min at 4°C.

**FIGURE 7.** Chromatography of ClqR on Sepharose CL-6B. Radiolabeled ClqRII was first incubated with buffer or digested with chondroitinase ABC, as described in Materials and Methods, and then chromatographed in Sepharose CL-6B (0.5 X 120 cm).
that a proteoglycan constitutes a part of the complex. However, amino acid analysis together with the glucosamine-to-galactosamine ratio and the insensitivity of the Clq receptor to digestion with chondroitinase seem to distinguish the Clq receptor from the serum Clq inhibitor, which has been previously characterized as chondroitin 4-sulfate proteoglycan (31). It is likely, however, that the ClqR and serum Clq inhibitor represent functional counterparts, in as much as both macromolecules are able to inhibit most of the Clq-dependent biologic reactions (23). Upon electrophoresis on SDS gels, the ClqR was shown to consist of a single protein band of 80–90,000 mol wt which, upon reduction, stains heavier, with a single band of ~60–70,000 mol wt. The ultracentrifugation data and the SDS-PAGE profile taken together suggest that the ClqR is a polymeric structure consisting of a protein portion noncovalently linked to a proteoglycan.

The biological significance of the receptor cannot be determined from these studies. It is clear, however, that the receptor does bind only to free Clq. Upon activation of the classical pathway of complement by immune complexes, C1-INa, the plasma inhibitor of activated C1, binds to C1r and C1s to form an irreversible complex, and thus readily dissociates them from the C1q molecule. Under these conditions, the collagenous tail of the C1q molecule becomes exposed and possibly available to bind to cell surface receptors on monocytes, lymphocytes, or polymorphonuclear cells (PMN), though this type of Clq is believed to be conformationally changed (38). Whether binding of a Clq-

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**TABLE IV**

*Inhibition of Clq-dependent Cytotoxicity by ClqR*

<table>
<thead>
<tr>
<th>Reaction mixture</th>
<th>Percent 51Cr release*</th>
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<tr>
<td>Raji + 51Cr-Ec</td>
<td>5</td>
</tr>
<tr>
<td>Raji + 51Cr-Ec + Clq</td>
<td>74</td>
</tr>
<tr>
<td>Raji + (ClqR + 51Cr-Ec + Clq)</td>
<td>10</td>
</tr>
</tbody>
</table>

* 1 x 10⁵, 51Cr-labeled, Clq-coated E, target cells were incubated with 5 x 10⁵ Raji cells in the presence or absence of 5 µg/ml ClqR in a total volume of 0.3 ml RPMI plus 5% FCS for 20 h at 37°C in an atmosphere of 95% air and 5% CO₂. After incubation, cells were centrifuged and the radioactivity of both pellet and supernatant determined. Cell damage is expressed as percent of total radioactivity released from the cells into the supernatant.

**TABLE V**

*Reduction of Clq Hemolytic Activity by ClqR*

<table>
<thead>
<tr>
<th>Reaction mixture</th>
<th>Percent hemolysis</th>
<th>Percent inhibition*</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Clq + GVB) + ClqD + EA*</td>
<td>89</td>
<td>--</td>
</tr>
<tr>
<td>(Clq + ClqR) + ClqD + EA</td>
<td>40</td>
<td>55*</td>
</tr>
</tbody>
</table>

* Highly purified Clq was incubated either with GVB or 5 µg/ml ClqR before addition to Clq-depleted serum (ClqD) in the presence of 20 mM CaCl₂. Hemolysis was expressed as percent of NHS-induced hemoglobin release.  
* The effect of ClqR is limited in part by the concentration of detergent (NP-40).
containing immune complex to a phagocytic cell Clq receptor represents one mechanism of immune clearance remains to be investigated. The binding of free Clq to cells possessing receptors for Clq promotes biological functions, as is apparent from studies which found that $^{51}$Cr-labeled, Clq-Fe could be lysed by Raji cells as well as by lymphoblastoid cells in the absence of anti--target cell antibody (15). This Clq-mediated cellular cytotoxicity could be inhibited if the Clq-coated target cells were first pretreated with ClqR (15). In addition, Clq has been reported (18-20) to inhibit collagen-dependent platelet aggregation and serotonin release. Whether this inhibition is mediated by a specific platelet receptor for Clq or if the platelet recognizes the collagen portion of the Clq through a specific receptor for collagen is not clear. The Clq receptor isolated from Raji cells is similar if not identical to the receptor on PMN or platelets, as has been confirmed through immunoprecipitation studies using Clq-coated Sepharose beads and murine monoclonal antibody raised to the receptor (manuscript in preparation). More work is needed to determine the precise function of cellular Clq receptor.

Summary

We have shown previously that an activity which is capable of precipitating purified Clq and inhibiting some of the Clq-dependent biologic reactions could be solubilized from the membranes of both normal human peripheral B lymphocytes and a B cell--derived lymphoblastoid cell line (Raji), both of which are known to possess receptors for human Clq. In this report we present evidence that this membrane-associated Clq inhibitor is a chondroitinase-insensitive macromolecule and is the receptor for human Clq. The receptor was solubilized from membranes of Raji cells with Nonidet P-40 and purified to homogeneity using Clq-Sepharose 4B affinity chromatography. Equilibrium density gradient centrifugation analysis revealed that the complex could be resolved into a protein-rich, low density fraction and a carbohydrate-rich, high density fraction. The large hydrodynamic size, coupled with the high buoyant density, suggests that a proteoglycan is a constituent of the complex and indicates that the receptor might be a macromolecular complex of a proteoglycan portion noncovalently linked to a 60--70 kD glycoprotein. The glycoprotein moiety, in turn, consists of two or more identical (70,000 mol wt) polypeptide chains held together by disulfide bonds and constitutes the Clq receptor (ClqR). Sucrose density ultracentrifugation analysis showed that the isolated receptor sediments with an apparent rate of 4.2 S. Immunochemical analyses demonstrated that a typical preparation of the ClqR complex consists of ~23% uronic acid and ~21% galactosamine with a galactosamine-to-glucosamine ratio of 3.2. Binding of Clq to the receptor was found to be optimal at low ionic strength and neutral or near-neutral pH (7--7.4). The isolated receptor was found to inhibit Clq hemolytic function, abrogate Clq-dependent rosette formation, and block the Clq-dependent, cell-mediated cytotoxicity, all of which are activities mediated by the receptor.

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References

22. Sim, R. B., G. J. Arlaud, and M. G. Colomb. 1979. CT inhibitor-dependent dissocia-


