Synthesis and Localization of Two Sulphated Glycoproteins Associated with Basement Membranes and the Extracellular Matrix

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ABSTRACT Two sulphated glycoproteins (sgps) of apparent molecular weight (Mr) 180,000 and 150,000, are synthesized by murine PYS and PF HR9 parietal endoderm and Swiss 3T3 cells. The Mr 150,000 sgp has a similar chemical structure to the sulphated glycoprotein, C, synthesized and laid down in Reichert's membrane by mouse embryo parietal endoderm cells (Hogan, B. L. M., A. Taylor, and A. R. Cooper, 1982, Dev. Biol., 90:210-214). Both the Mr 180,000 and 150,000 sgps are deposited in the detergent-insoluble matrix of cultured cells, but they do not apparently undergo any disulphide-dependent intermolecular interactions and are not precursors or products of each other. They contain asparagine-linked oligosaccharides, but these are not the exclusive sites of sulphate labeling. Antiserum raised against the Mr 150,000 sgp C of Reichert's membranes has been used in an immunohistochemical analysis of rat skin. In early foetal and adult skin the antigen is present only in basement membranes, but transiently before and after birth it is also found throughout the upper part of the dermis. This suggests that 150,000 sgp C is at times synthesized by nonepithelial cells and contributes to the extracellular matrix of mesenchymal tissues.

Basement membranes are thought to play an important role in both establishing and maintaining tissue organization. The major components so far identified are Type IV procollagen, laminin (GPI and GP2), and heparan sulphate proteoglycan of Mr > 5 x 10^5 (1-6). More recently, sulphated glycoproteins (sgps) of Mr ~ 180,000 and 150,000 have been added to the list. Thus, Carlin et al. (7) have isolated a Mr 158,000 glycoprotein (gp), entactin, from the membrane sacs made by the murine parietal endoderm cell line, M1536-B3. Entactin was reported to be the major matrix gp labeled after incubating these cells with [35S]sulphate. In vivo, entactin has been localized in a variety of basement membranes including kidney tubules, where the highest concentration is found immediately beneath the epithelial cell layer (7, 8).

While studying the biosynthesis of heparan sulphate proteoglycan by normal parietal endoderm (PE) cells from mouse embryos (6), we observed two heparitinase and chondroitin ABC lyase-resistant, sulphated glycoproteins (sgps) of Mr 175,000 and 145,000 in the basement membrane (Reichert's membrane) laid down by these cells. The lower molecular weight sgp appeared to be the same as the Mr 150,000 gp, C, originally described by us as immunoprecipitated from the culture medium of PE cells with antilaminin serum (4, 9). In the present paper, we report on the sgps of the murine parietal endoderm cell line, PYS. These cells incorporate some [35S]-sulphate into the A- and B-chains of laminin and into the 150,000-Mr gp C. However, we find that the major sgp incorporated into the extracellular matrix has a Mr of 180,000. Extending these studies to other cultured murine cell lines, we found that Swiss 3T3 and STO cells also make Mr 180,000 and 150,000 sgps.

Antiserum raised against purified denatured Mr 150,000 sgp C has been used to localize the antigen in rat skin at different times of development. In adult and early fetal tissue, the antigen is restricted to basement membranes. However, during late embryonic stages and until 10 d after birth, 150,000-Mr sgp C is also present throughout the upper part of the dermis. This suggests that the 150,000-Mr sgp is at times synthesized by nonepithelial cells, and contributes to the extracellular matrix of mesenchymal tissues.
MATERIALS AND METHODS

Cell Culture and Radioactive Labeling

Teratocarcinoma-derived PYS (10) and PFHR-9 (11) parietal endodermal cells were obtained from Drs. J. Lehman (University of Colorado Medical Center, Denver, CO) and R. Oshima (La Jolla Cancer Research Foundation, La Jolla, CA), respectively. Swiss 3T3 cells (12) were from stocks held by the Cell Production Unit, National Cancer Institute, Bethesda, MD. STO is a thigoguanine and ouabain-resistant line derived from 15-17-d-old SIM mouse embryo cells (13). It was originally obtained from Dr. A. Berns (Ontario Cancer Institute, Toronto, Canada). All cells were cultured in Dulbecco's modified Eagle's medium (DME) in 10% fetal bovine serum (FBS).

For labeling with [35S]methionine (Met), cultures of ~3 x 10^6 cells in 35-mm tissue culture dishes were washed twice with DME without Met (DME-Met) and then incubated with 0.5 or 1.0 ml of DME containing 1 µCi/ml cold Met, 10% dialyzed FBS, and 100-200 µCi/ml [35S]Met (Amersham International; sp act 1,000 Ci/mmol).

For labeling with [35S]SO4, cultures of similar density in 35-mm dishes were washed twice with DME in which the MgSO4 had been replaced with MgCl2 (DME-SO4) containing 10% dialyzed FBS and 200-500 µCi/ml [35S]SO4 (Amersham International, Amersham, Bucks, England; sp act 30-50 Ci/mmol).

Tunicamycin (Sigma Chemical Co., St. Louis, MO) was prepared as a stock solution in dimethyl sulphoxide, and added to cells in DME containing only 1% FBS, at final concentrations of 5 or 25 µg/ml. These concentrations inhibited protein synthesis by 35% and 14% respectively. Control experiments showed that the minimum dose for complete inhibition of N-glycosylation of laminin in PYS cells and agpC in 3T3 cells was 1 µg/ml; higher doses gave no further change in electrophoretic mobility.

Cell Fractionation

At the end of the labeling period the culture medium was removed, centrifuged to remove cells and debris, and phenyl methyl sulphonylfluoride (PMSF), and N-ethylmaleimide (NEM) added to a final concentration of 2 and 5 mM, respectively. The cell layer was washed twice with 2 ml of Dulbecco's phosphate-buffered saline (PBSA), the dish placed on ice, and 500 µl of lysis buffer (0.15 M NaCl, 0.005 M EDTA, 0.05 M Tris, pH 8.0, 1% (vol/vol) Nonidet P-40 (NP-40), containing 0.002 M PMSF and 0.005 M NEM) added gently. After 10 min the cytoplasmic fraction was removed and centrifuged at 10,000 rpm for 10 min at 4°C. This detergent soluble fraction contained 92% of the total, cell-associated, acid-precipitable radioactivity after incubating cells for 2.25 h with [35S]Met. The detergent-insoluble material remaining attached to the culture dish was washed with 2 ml of 0.01 M Tris-HCl, pH 6.8, at 4°C, and solubilized in 200 µl of electrophoresis sample buffer (see below) containing 2-mercaptoethanol at 100°C.

Polyethylene Glycol and Immunoprecipitation

Polyethylene glycol Mr 6,000 (Koch Light) was added to the culture medium to give a final concentration of 10% (wt/vol), together with 50 µg/ml gelatin (Sigma Chemical Co.; swine skin Type 1) as carrier. After 4 h at 4°C, the precipitate was collected by centrifugation, washed twice with 70% aqueous ethanol, and dissolved in electrophoresis sample buffer (see below).

Immunoprecipitation was carried out essentially as described (9), using 5-10 µl of antiserum and 30-50 µl of a 50% suspension of protein A-Sepharose (Pharmacia Fine Chemicals, Uppsala, Sweden) in 1 ml of 0.4 M NaCl, 0.005 M EDTA, 0.005 M Tris, pH 8.0, 1% (vol/vol) NP-40.

Collagenase Digestion

High molecular weight molecules precipitated with 10% polyethylene glycol from the medium of 3 x 10^6 cells labeled for 19 h with [35S]Met or -SO4 were resuspended in 50 µl buffer (0.5 M NaCl, 0.5 mM CaCl2, 0.05 M Tris, pH 7.5, with 5 mM NEM and 2 mM PMSF) with or without collagenase (Advance Biofactures Corp., Lynbrook, NY; Form III) at a concentration of 50 U/ml. The samples were incubated at 37°C for 2 h before analysis by SDS PAGE. All of the Type IV procollagen present was digested in this time.

SDS PAGE

This was carried out as described (9) by the method of Laemmli (14) using 5%--10% gradient slab gels. Electrophoresis sample buffer contained 2% (wt/vol) SDS, 10% (vol/vol) glycerol, 0.0625 M Tris, pH 6.8, and, unless otherwise stated, 5% (vol/vol) 2-mercaptoethanol. All samples were heated to 100°C for 3 min. Photographs were carried out as described (9).

Immunoblotting

The method used was essentially that described by Towbin et al. (15). Approximately 20 µg of total protein from Reichert's membranes solubilized in 2% SDS, 0.0625 M Tris, pH 6.8, 5% 2-mercaptoethanol at 100°C (C), or 2 µg fibronectin isolated from human plasma by chromatography on gelatin-Sepharose (16) were analyzed on a 6% polyacrylamide slab gel under reducing conditions. Proteins were transferred to nitrocellulose using a constant current of 100 mA for 13--16 h and recovery assessed by staining with p-aminocoumarin staining of the nitrocellulose sheet with Amido Black and the polyclonal antibody gel with Coomassie Blue. The remaining nitrocellulose sheet was soaked in 3% haemoglobin in PBSA for 2 h, and strips then incubated with serial dilutions of antiserum (1:100-1:400) in 5 ml 3% Hb in PBSA for 2 h at room temperature. After extensive washing, the strips were incubated with 0.2 µCi [35S]protein A (Amersham International; sp act 30 mCi/ml) in 5 ml 3% Hb in PBSA at room temperature for 2 h. Autoradiography was at ~70°C using Fuji x-ray film and intensifying screens.

Antisera

Rabbit anti-hamster LETS protein (fibronectin) serum used for immunoprecipitation and immunoblotting experiments was kindly provided by Dr. R. O. Hynes (Center for Cancer Research, Department of Biology, Massachusetts Institute of Technology). Rabbit anti-mouse M, 150,000 gp C (anti-C) serum was obtained by immunizing rabbits with denatured C-chains isolated from Reichert's membranes and purified by SDS PAGE (9). The antiserum shows no cross-reactive bands with mouse or human fibronectin.
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Peptide Mapping

This was by a modification of the method of Cleveland et al. (17) as described previously (9).

In Vitro Translation of STO Cell mRNA

Total cellular RNA from STO cultures was prepared as previously described (18). For in vitro protein synthesis, 20 μl of nucleoside treated rabbit reticulocyte lysate (a gift of Dr. J. Jenkins, Imperial Cancer Research Fund) was incubated at 30°C for 3 h in a final volume of 30 μl containing 10–30 μCi [35S]Met, 0.2 mg/ml total cellular RNA, 50 μM of all amino acids except Met, 37.5 μg/ml calf liver tRNA, 37.5 μg/ml creatine kinase, 10 mM creatine phosphate, 5 mM 2-aminopurine, 0.1 mM spermine, 100 mM KCl, and 0.5 mM MgCl2. Dog pancreas microsomal membranes were kindly provided by Dr. M. Owen (Imperial Cancer Research Fund) (19) and were added at a concentration of 9.6 A260 U/25 μl of total reaction mix.

Immunohistochemistry

Frozen sections of rat skin were prepared using previously described methods (20), but with paraformaldehyde fixation of the tissue after sectioning rather than before freezing. The anti-C serum was used at a 1:30 dilution. For antigen absorption experiments 1 μg 150,000 sgp C purified from Reichert’s membranes by gel electrophoresis (9) was added to 30 μl of diluted anti-C serum and left overnight at 4°C before use. The preparation and characterization of the antiserum and reagents have been fully described elsewhere (21). Fluorescein isothiocyanate anti-rabbit IgG serum was obtained from Miles Laboratories (Slough, Bucks, England) and was used at a 1:50 dilution. Photographs were taken on a Leitz Ortholux II microscope fitted with epi-illumination on Ilford HP5 film. The exposure and development times were identical for each micrograph.

RESULTS

Sulphated Glycoproteins in the Culture Medium of PYS Cells

Confluent cultures of PYS cells were labeled with either [35S]Met or [35S]SO4. Equal aliquots of the culture medium were then treated with either polyethylene glycol, to precipitate high molecular weight molecules, or immunoprecipitated with antisera raised against proteins isolated from Reichert’s membranes. Anti-LC serum reacts with the A- and B-chains of laminin and the 150,000-Mr gp C, while anti-C serum reacts only with the 150,000 gp C (Fig. 1). As shown in Fig. 2, the major [35S]Met labeled high molecular weight proteins secreted by PYS cells are laminin (Mn, 450,000 A-chains and Mₙ, 230,000-240,000 B-chains) and α₄ and α₂ Type IV procollagen (Mn, 195,000 and 190,000) (9, 22). Labeling with [35S]SO₄ reveals the synthesis of very high molecular weight heparan-sulphate proteoglycan (6, 22), some of which migrates into the top of the gel, and a prominent Mn, 180,000 sulphated species (Fig. 2, lane 2). This 180,000-Mr band is not sensitive to reduction or denaturing gels, or by immunoprecipitation. Lanes 4 and 5, but [35S]SO₄ label. Lane 8: [35S]Met-labeled polypeptides immunoprecipitated with anti-C serum. Lane 9: As for lane 8 using preimmune serum. Lane 10: As for lane 9 using [35S]SO₄-labeled medium.

reaction with fibronectin in either 1% immunodiffusion gels or by immunoblotting (Fig. 1). It does not react with Type IV procollagen either by immunoblotting (Fig. 1) or by immunoprecipitation (see Fig. 2). Unabsorbed serum does have weak cross-reaction with reduced and alkylated laminin, as described (9). However, after absorption with native Engelbreth-Holm-Swarm (EHS) sarcoma laminin (kindly supplied by Dr. R. Timpl, Max. Planck Institut Fur Biochemie, Martinsried, Federal Republic of Germany) covalently coupled to Sepharose (20 μg/100 μl of antiserum), the antiserum reacts only with the 150,000-Mr gp C component of total Reichert’s membrane protein, as shown by immunoblotting (Fig. 1). This absorbed antiserum is designated anti-C’. Rabbit anti-mouse laminin and 150,000-Mr gp C (anti-LC) serum was obtained by immunizing rabbits with native laminin and Mn, 150,000 gp C isolated from Reichert’s membranes (9). The antiserum shows no cross-reaction with fibronectin either in 1% immunodiffusion gels or by immunoblotting (Fig. 1). The antiserum does not react with Type IV procollagen, either in 1% immunodiffusion gels, or by immunoprecipitation (Fig. 2) or immunoblotting (Fig. 1). Immunoblotting experiments show that it reacts with both the A- and B-chains of laminin and the Mn, 150,000 C polypeptide (Fig. 1). Affinity purified rabbit anti-EHS sarcoma laminin was kindly provided by Dr. R. Timpl. This does not react with M, 150,000 C (Fig. 1).

FIGURE 2 Sulphated macromolecules secreted by PYS cells. 3 X 10⁶ PYS cells were labeled for 16 h in 0.5 ml of medium containing either 100 μCi [35S]Met or 400 μCi [35S]SO₄. At the end of the incubation, 60-μl aliquots of the medium were used for the isolation of high molecular weight components with 10% polyethylene glycol or for immunoprecipitation. Lanes 1-7 are from one experiment, lanes 8-10 from another. Lane 1: [35S]Met-labeled proteins precipitated with 10% polyethylene glycol. The α₁ and α₂ Type IV procollagen polypeptides (IV) migrate close to the B-chains of laminin. They could be clearly resolved on shorter exposure of the gel to film. The exposure in this figure was 16 h. Lane 2: [3sS]SO₄-labeled material precipitated with 10% polyethylene glycol. The heterogeneous material migrating near the top of the gel is heparan sulphate proteoglycan (6). Film exposed for 10 d. Lane 3: [14C]-[abeled protein of Mₙ, standards proteins (Amersham International). These are heavy chains of myosin (212,000), phosphorylase b (100,000 and 92,500), bovine serum albumin (69,000), ovalbumin (46,000) carbonic anhydrase (30,000) and lysozyme (14,300). Lane 4: [3sS]Met-labeled polypeptides immunoprecipitated with anti-LC serum. Film exposed for 16 h. Lane 5: [3sS]Met-labeled polypeptides immunoprecipitated with anti-C serum. Film exposed for 2 d. Lanes 6 and 7: As for lanes 4 and 5, but [3sS]SO₄ label. Lane 8: [3sS]Met-labeled polypeptides immunoprecipitated with anti-C’ serum. Lane 9: As for lane 8 using preimmune serum. Lane 10: As for lane 9 using [35S]SO₄-labeled medium.
**Sulphated Glycoproteins in the Cell Layer of PYS and PFHR9 Cultures**

We next investigated whether the sulphated M₄ 180,000 and 150,000 species described above are also present in the extracellular matrix laid down by PYS and PFHR9 cultures. Cells were labeled with [³⁵S]Met or [³⁵S]SO₄, and the cytoplasm extracted with buffer containing the nonionic detergent NP-40. The detergent-insoluble residue attached to the culture dish was then analyzed by SDS-PAGE. As shown in Fig. 3, lane 1, this residue contains many [³⁵S]Met-labeled proteins, including myosin and actin. However, only three sulphated components are present; very high molecular weight heparan sulphate proteoglycan, a prominent 180,000-M₄ species, and a minor 150,000-M₄ band (Fig. 3, lane 2). The 150,000-M₄ component comigrates with the [³⁵S]Met-labeled polypeptide C in the culture medium immunoprecipitated with anti-C serum (Fig. 3, lane 3). Similar results were obtained with the cell line PFHR9 (Fig. 3, lanes 4-6), and with PYS cultures that were either subconfluent or dense (not shown). The inhibitor tunicamycin was used to investigate whether

![Figure 3](https://example.com/figure3.png)

**Figure 3** Sulphated macromolecules in the detergent insoluble residue of PYS and PFHR9 cells. 3 x 10⁶ cells were labeled for 20 h in 1.0 ml of medium with either 100 µCi [³⁵S]Met or 200 µCi [³⁵S]-SO₄. After collecting the medium, the cells were washed and the cytoplasm extracted in 500 µl of buffer containing 1% NP-40. The detergent-insoluble residue remaining on the dish was washed, and solubilized in electrophoresis sample buffer at 100°C. Lane 1: [³⁵S]Met-labeled polypeptides in the detergent-insoluble residue. The heavy chain of myosin and actin are marked with arrows. Lane 2: [³⁵S]SO₄-labeled components of the detergent-insoluble residue. Lane 3: [³⁵S]Met-labeled polypeptides immunoprecipitated from 400 µl culture medium with anti-C serum. Lanes 4-6: As above, but using PF HR9 cultures.

the M₄ 180,000 sulphated protein deposited in the matrix of PYS cells contains asparagine-linked carbohydrate residues, as shown earlier for the basement membrane sgps synthesized by normal parietal endoderm cells (6, 9). Tunicamycin reduces the M₄ of the 180,000 sulphated protein to ~176,000, but does not abolish the sulphate labeling (Fig. 4a). To see if the M₄ 180,000 and 150,000 sgps in the matrix are part of a higher molecular weight disulphide bonded complex or network, the [³⁵S]SO₄-labeled detergent insoluble residue was analyzed under reducing and nonreducing conditions. This produced only a small change in the migration of the M₄ 180,000 and 150,000 sgps (Fig. 4b). The possibility was also considered that the M₄ 180,000 and 150,000 sgps are precursors or products of each other. Some evidence against such a relationship comes from the results of the pulse-chase experiment described in Fig. 4c, which shows that over 24 h there was no apparent conversion of the 180,000 sulphated protein in the matrix into material with a M₄ of 150,000. The results of *Staphylococcus aureus* V8 protease digestion of the two sgps is shown in Fig. 5. The larger, [³⁵S]Met labeled cleavage products differ in M₄ by ~30,000. Some comigrating smaller peptides are also generated (open arrows).

**Extracellular Sulphated Glycoproteins Synthesized by Swiss 3T3 and STO Cells**

In a survey of different cell lines, we found that Swiss 3T3 cells synthesize and secrete 150,000 sgpC (Fig. 6). Immunoprecipitation of the culture medium with anti-LC serum reveals that these cells also synthesize some M₄ 180,000 sgp, but less, relative to the 150,000 species, than PYS cells (not shown). Antifibronectin serum does not react with the M₄ 150,000 and 180,000 sgps secreted by 3T3 cells (Fig. 6, lane 2).

In the cytoplasmic fraction of 3T3 cells labeled for 2 h with [³⁵S]Met, gp C exists as two species, of M₄ ~150,000 and 145,000 (Fig. 6, lane 6). By analogy with experiments on endoderm cells (9), the larger molecules are those which have undergone terminal glycosylation in the Golgi apparatus, while the smaller ones are partially glycosylated molecules not yet fully processed. Both in the medium (Fig. 6, lane 3) and cytoplasmic fraction (not shown), [³⁵S]SO₄ label is associated only with the larger 150,000 molecules. After treating 3T3 cells with tunicamycin, the glycoprotein C secreted into the culture medium has a M₄ of ~145,000 and is still labeled with [³⁵S]-SO₄ (Fig. 6, lanes 4 and 7). Immunoprecipitation of the cytoplasmic fraction of tunicamycin treated cells labeled with [³⁵S]Met for 2 h reveals two C polypeptides, both of which migrate faster than the corresponding chains in untreated cells (Fig. 6, track 8). Control experiments gave identical results with between 1 and 5 µg/ml tunicamycin (see also Fig. 6, lane 9), and showed that these doses yielded only single intracellular precursors of laminin A₁, B₁ and B₂-chains in PYS cells (9).

To test the possibility that the rate of synthesis of 3T3 sgps varies with cell density, sparse, touching, and confluent cultures were labeled with [³⁵S]Met and aliquots of the culture medium containing equal amounts of acid precipitable radioactivity were immunoprecipitated with anti-C serum. As shown in Fig. 7, there does not appear to be a significant change in the specific accumulation of the 150,000 sgp in the culture medium with cell density. Similarly, the ratio of the M₄ 180,000 and 150,000 sgps in the detergent insoluble residue attached to the culture dish was apparently unaffected by cell density.

As with PYS cells, the 150,000 sgp in the medium and cytoplasm of 3T3 cells is not disulphide bonded into higher
FfGURE 4 Sulphated glycoproteins in the detergent-insoluble matrix of PYS cells. (a) Effect of tunicamycin. 3 x 10^6 PYS cells were preincubated for 3.5 h with or without 5 μg/ml tunicamycin. The cells were then labeled for 10 h with 400 μCi [35S]SO4 in 0.5 medium, also in the presence or absence of inhibitor. The detergent-insoluble residue was isolated and analyzed under reducing conditions. Lane 1: [35S]-labeled M, standard proteins (arrowed). Lane 2: Detergent-insoluble residue of control cells. Lane 3: Detergent-insoluble residue of cells incubated with tunicamycin. (b) Absence of disulphide bonding. Dense cultures of PYS cells (~1 x 10^6/35-mm dish) were labeled for 11 h in 1 ml of medium containing 200 μCi [35S]SO4. The detergent-insoluble residue was prepared as described, and solubilized in SDS electrophoresis sample buffer with or without 2-mercaptoethanol. Equal aliquots were analyzed on the same 5% gel. The similar intensity of the Mr 180,000 band in lanes 2 and 3 is evidence that the gp is as efficiently extracted from the matrix in the absence of 2-mercaptoethanol as in its presence. Lane 1: [35S]-labeled M, standard proteins (arrowed). Lane 2: [35S]SO4-labeled detergent-insoluble residue analyzed under reducing conditions. Lane 3: [35S]SO4-labeled detergent-insoluble residue analyzed under nonreducing conditions. (c) Pulse-chase analysis. Cultures of 4 × 10^5 PYS cells were labeled for 6 h in 0.5 ml of sulphate free medium containing 250 μCi of [35S]SO4. The medium was then removed, the cells washed, and incubation continued with 2 ml of DMEM containing the normal amount of MgSO4. 40-μl aliquots of the detergent-insoluble residue of each culture were analyzed under reducing conditions. Lane 1: [35S]SO4-labeled components of the detergent-insoluble residue after 6 h of labeling. Lane 2: As above, after 8.5-h chase. Lane 3: After 18-h chase. Lane 4: After 24-h chase. Molecular weight aggregates, although a small shift in electrophoretic migration is observed under nonreducing conditions (not shown). Further evidence for a similar chemical structure between the 150,000 sgp synthesized by 3T3 cells and parietal endoderm cells comes from a comparison, by one-dimensional SDS cell electrophoresis, of the peptides generated by *S. aureus* V8 protease digestion (Fig. 8).

Similar results were obtained using the murine STO cell line, and Swiss 3T6 cells (not shown).

**In Vitro Translation of Messenger RNA for 150,000 Glycoprotein C**

Total RNA, isolated from STO cells, was translated in the rabbit reticulocyte lysate with or without supplementation by dog pancreas microsomal membranes. Polypeptides were then immunoprecipitated from the total translation products using anti-C serum, and analyzed by SDS gel electrophoresis. As shown in Fig. 9, the in vitro synthesized C polypeptide has a Mr equal to 140,000 (Fig. 9, lane 3). Translation in the presence of microsomal membranes yields a C polypeptide with a Mr of ~143,000 (Fig. 9, lane 2).

**Immunohistochemical Localization of 150,000 sgp C in Rat Skin**

Frozen sections of rat skin at various developmental stages were stained by indirect immunofluorescence using anti-C serum. In 15-18-d old embryos, the 150,000 sgp is located only in basement membranes (Fig. 10a). However, at later stages of prenatal development until ~10 d postpartum, there is staining of short fibrils throughout the papillary dermis (Fig. 10c). This pattern is in addition to, and quite distinct from, the staining of basement membranes, including those of capillaries. It is also distinct from the pattern obtained with antifibronectin serum (Fig. 10b). The reticular dermis does not show staining with anti-C serum at this stage. Anti-C serum preabsorbed with purified M, 150,000 sgp C antigen gave negative results on skin of all ages (Fig. 10d), but staining was not removed by preadsorption with EHS sarcoma laminin (not shown). In adult rats, the pattern of staining is the same as that of 15–18-d old embryos (not shown).

**DISCUSSION**

Here we show that murine PYS and PFHR9 parietal endoderm, and Swiss 3T3, cells synthesize two extracellular matrix sgps of Mr 180,000 and 150,000. These appear to be the same as the two sgps made by mouse embryo parietal endoderm cells and deposited in vivo into the underlying Reichert's membrane (6). The 150,000 sgp C is probably the same as entactin, a basement membrane Mr 158,000 sgp recently described by Carlin et al. (7). However, the Mr 180,000 sgp has not previously been identified as a product of cells in culture. In addition, our novel observation that the A- and B-chains of PYS laminin are sulphated (Fig. 1, lane 6) and the sulphation of fibronectin (Fig. 6 and reference 23), raise the possibility that sulphation of noncollagertous extracellular matrix gps is a
FIGURE 5. S. aureus V8 proteinase digestion of 150,000 and 180,000 sgp s made by PYS cells. 3 x 10^5 PYS cells were incubated for 5 h in 0.5 ml of medium containing 250 /iCi [35S]Met. The medium was immunoprecipitated with antilaminin serum and the samples fractionated on a 5-7.5% gradient SDS polyacrylamide gel. Bands corresponding to the Mr 180,000 and 150,000 sgp s were cut out and digested with S. aureus V8 protease at 37°C for 2 h. The digests were analyzed on a 10-15% gradient gel. Lanes 1-3: 180,000 sgp digested with 0, 10, and 100 /ig/ml V8 protease, respectively. Lane 4: [14C]-labeled Mr standard proteins (from New England Nuclear). Lanes 5-7: 150,000 sgp digested with 100, 10, and 0 /ig/ml V8 protease, respectively. The position of possible common peptides is marked with open arrows, and the approximate M, s of the major cleavage products indicated.

rather general phenomenon.

Two lines of evidence argue against a precursor-product relationship between the Mr, 180,000 and 150,000 sgp s. Firstly, anti-C serum recognizes only a single polypeptide of Mr, 140,000 or 143,000 when RNA from STO cells (Fig. 9) or normal parietal endoderm cells (M. Kurkinen, unpublished results) is translated in vitro in the absence or presence of microsomal membranes, respectively. Secondly, there appears to be no interconversion of the two species in the matrix of PYS cells during a pulse-chase experiment (Fig. 4c). The one-dimensional peptide maps obtained by S. aureus V8 proteinase digestion (Fig. 5) are consistent with the larger sgp being a precursor of the smaller. However, taken with the other results, they can also mean that the two species are discrete proteins which share common sequences but differ by a 30,000-polypeptide extension.

Anti-C' serum, which has been absorbed with EHS sarcoma laminin and does not react with A- and B-chains by immunoblotting (Fig. 1), nevertheless immunoprecipitates laminin from the culture medium of PYS cells. Similarly, antilaminin serum, which does not react with 150,000 C (Fig. 1) immunoprecipitates C from the culture medium of PE cells (4). These results...
FIGURE 8. *S. aureus* V8 proteinase digestion of 150,000 glycoprotein C from 3T3 cells and normal parietal endoderm cells. $3 \times 10^6$ 3T3 cells and 30 Reichert's membranes dissected from 13.5-d-old mouse embryos (4) were labeled for 16 h with 200 #Ci [35S]Met. The medium was then immunoprecipitated with anti-C serum, and the samples fractionated on a 5–10% gradient SDS polyacrylamide gel. Bands corresponding to the 150,000 gp C were cut out and digested with *S. aureus* V8 protease at 37°C for 2 h. The digests were analyzed on a 10–15% gradient gel. Lanes 1–3: 150,000 sgp from 3T3 cells digested with 100, 10, and 0 #g/ml of V8 protease respectively. Lanes 4–6: 150,000 sgp from normal parietal endoderm cells digested with 0, 10, and 100 #g/ml of V8 protease respectively.

FIGURE 9 In vitro translation of gp C from total RNA of STO cells. Total cellular RNA isolated from STO cultures was translated in the nuclease treated rabbit reticulocyte lysate with and without dog pancreas microsomal membranes as described in Materials and Methods. Lane 1: Total in vitro synthesized polypeptides. Lane 2: Translation in the presence of membranes, immunoprecipitated with anti-C serum. Lane 3: Translation in the absence of membranes, immunoprecipitated with anti-C serum. Lane 4: [14C]-labeled M r standard proteins (Amersham International).

FIGURE 10 Antigen localization in rat skin by indirect immunofluorescence. (a) Distribution of the 150,000 sgp in 18-day rat embryo skin. The staining is restricted to basement membranes of the dermal/epidermal junction, including a developing hair follicle (arrow), and around capillaries and nerve and muscle fibers. e, epidermis. (b) Fibronectin distribution in neonate rat skin, characterized by widespread fibrillar staining of the dermis. The hair follicle (h) and epidermis are not stained. (c) 150,000 sgp distribution in neonate rat skin. In addition to basement membrane staining of the dermal/epidermal junction and capillaries (cf a) fine fibrils containing 150,000 sgp are visible (arrow). (d) Section of neonate rat skin treated with anti-C serum preabsorbed with the 150,000 sgp C. No positive stain is visible. The dermal/epidermal junction is pointed out by an arrow. Bars, 20 #m. $\times 460$. 

HOGAN et al. Extracellular Matrix Sulphated Glycoproteins
suggested that laminin and 150,000 sgp C form a noncovalent complex resistant to dissociation in 0.4 M NaCl (as used in the immunoprecipitation reaction). Carlin et al. (7) have also reported that laminin (GP1 and GP2) and entactin are immunoprecipitated as a complex from the medium of M1536-B3 parietal endoderm cells. It seems likely that in the culture medium these proteins would also form a complex with heparan-sulphate proteoglycan, since laminin binds to heparin at physiological salt concentrations (24).

Although 3T3 cells have been shown by radioimmune assay to synthesize laminin (3) this is the first report that these cells also produce 150,000 sgp C (entactin). Experiments described in this paper provide some information about the intracellular processing of this gp. Tunicamycin reduces the Mr of the secreted and intracellular polypeptides, but does not abolish labeling with [35S]Met. This suggests that asparagine-linked oligosaccharides are present in the molecule, but are not the exclusive site of sulphation. Further evidence for the presence of N-linked oligosaccharides in C-chains comes from earlier experiments on the sensitivity of intracellular molecules to digestion by Endo-β-N-acetylglucosaminidase (Endo-H) (9). The observation that two intracellular polypeptides are present after labeling tunicamycin-treated cells with [35S]Met for 2 h (Fig. 6, lanes 8 and 9) suggests that the protein contains O-linked oligosaccharides, which may be sulphated. The unmodified C polypeptide synthesized in vitro in the rabbit reticuloendothelial processing.

When anti-C serum was used to investigate the distribution of the 150,000 sgp C in rat skin, two quite distinct patterns were seen. In embryonic and adult animals, staining is confined to regenerating mouse liver. Taken together, these results point to a role for 150,000 sgp C and laminin in mesenchymal tissues from 15-17-d old mouse embryos (12, 13) and are generally consistent with results of antibody localization studies (14). Thus it appears that gp C and entactin are identical molecules.


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Note Added in Proof: We have now observed that antientactin serum, kindly provided by Dr. A. E. Chung (University of Pittsburgh), immunoprecipitates the 150,000 sgp C made by Swiss 3T3 cells. It therefore appears that gp C and entactin are identical molecules.

REFERENCES


