**Biosynthesis and Regulation of Type V Collagen in Diploid Human Fibroblasts**

(Received for publication, April 7, 1983)

A. Sampath Narayanan and Roy C. Page

From the Department of Pathology SM-30, School of Medicine, and Department of Periodontics, School of Dentistry and Center for Research in Oral Biology, University of Washington, Seattle, Washington 98195

The biosynthesis of type V collagen and its regulation were studied using diploid human gingival fibroblasts. Cells were metabolically labeled with radioactive amino acids and labeled proteins were subjected to limited pepsin digestion. DEAE-cellulose chromatography at 15 °C, and polyacrylamide gel electrophoresis. Proteins eluted from DEAE-cellulose columns by 0.25 M NaCl contained a collagen species which was resistant to mammalian collagenase and had α chains with hydroxylysine/lysine ratios and CNBr peptide patterns similar to α1(V) and α2(V). Procollagen(V) fractions obtained by DEAE-cellulose chromatography and immunoprecipitates of type V collagen antibody contained polypeptides with Mr = 239,000, 219,000, 198,000, 174,000, 157,000, and 132,000. By comparing the CNBr peptide maps of these proteins with those of standard α1(V) and α2(V) chains, the first three polypeptides were shown to be related to α1(V) and the others to α2(V). It was concluded that the gingival fibroblasts synthesize type V collagen, that the proα1(V) and proα2(V) chains have Mr = 239,000 and 174,000, respectively, and that the α1(V) and α2(V) chains laid in the form of fibrils have Mr = 198,000 and 132,000, respectively.

A detectable amount of type V collagen was synthesized only at high cell density, and it was associated with the cell layer. The amount and proportion of type V synthesized were increased when the cells were labeled in the presence of serum, and the increase was accompanied by a decrease in type III. This effect was dependent on serum concentration. Serum obtained from platelet-poor plasma failed to elicit this effect, and it was restored by the addition of platelet-derived growth factor. Platelet-derived growth factor was effective in medium with and without platelet-poor serum. Thus, it appears that platelet-derived growth factor may be an important regulatory factor in the synthesis of types V and III collagens.

The collagens represent a group of at least five closely related but genetically distinct structural proteins designated as types I, II, III, IV, and V (1). Types I and III are found in many connective tissues, whereas the presence of types II and IV is restricted to cartilage and basement membranes, respectively. Type V collagen was first isolated from fetal membranes (2); however, later studies revealed that it is present in most connective tissues along with types I and III or II (3), and that it has a unique ultrastructural localization in pericellular spaces and near basement membranes (4–6). The type V collagen appears to be involved in many important biological processes such as platelet aggregation, epithelial cell migration, substrate attachment, and binding of other interstitial collagen fibrils (7–12).

Many aspects of the structure and biosynthesis of type V collagen are not fully known. Pepsin digests of tissues contain α1 and α2 chains as the major type V components; however, their ratio varies from tissue to tissue and with the developmental stage of the animal (2, 3, 13). These and the thermal denaturation studies of Rhodes and Miller (3) indicate that type V collagen exists in two major molecular forms with chain composition (α1)3 and (α1)2α2. However, the pepsin extracts also contain an additional α3 chain (14–16), and it is not clear whether it is a constituent of type V molecules or not. Biosynthetic studies using cell and organ cultures have indicated that the type V collagen molecules laid down as fibrils may retain a significant portion of nonhelical peptide segments (17–19). These studies and the electron microscopic observations of Bachinger et al. (20) also indicate that the type V procollagen has larger globular extensions than procollagen type I, but both have similar sized helical regions. The proα1(V) and proα2(V) chains elaborated by a human rhabdomyosarcoma cell line have Mr = 220,000 and 150,000 (21), and whether these values hold true for normal cells as well is not known. Also nothing is known about mechanisms which regulate synthesis of type V collagen. An understanding of the regulatory mechanisms is important because abnormal amounts of type V collagen are present in many diseases such as atherosclerosis, chronic inflammation, and carcinomas (22–25).

We report here studies on the synthesis of type V collagen by diploid fibroblasts, which are the predominant cell type responsible for synthesis of collagens in the gingiva (26). Normal human gingiva contains α1, α2, and additional as yet unidentified type V chains, and the nature of the chain composition has not been resolved (27). The content and proportion of type V collagen is elevated several-fold in chronically inflamed gingiva (24). The studies described here were undertaken to determine the form and chain composition of type V collagen in gingiva and to investigate mechanisms which may regulate type V collagen biosynthesis and accumulation.

**MATERIALS AND METHODS**

Cell Culture and Labeling—Fibroblasts were obtained from explants of human gingiva from an individual with clinically and

*This work was supported by National Institutes of Health Grants DE-02600 and DE-03301. The costs of publication of this article were defrayed in part by the payment of page charges. This article must therefore be hereby marked "advertisement" in accordance with 18 U.S.C. Section 1734 solely to indicate this fact.
radiographically healthy periodontal tissues. Cells were maintained in and labeled as described previously (28). Briefly, confluent cultures in 75 cm² flasks were precipitated for 1 h in serum-free Dulbecco-Vogt medium containing 50 μg/ml each of ascorbic acid and 8-aminopropionitrile, and then labeled for 24 h in 5.0 ml of the same medium containing 10 μCi/ml each of [2-3H]proline (specific activity 20–40 Ci/mmol) and [2-3H]glycine (specific activity 30–60 Ci/mmol and 84–97% NaH2PO4, 150 mM NaCl buffer, pH 7.2, and then treated with 100 μl of a 1:10 diluted antiserum for 1 h at room temperature. Then 100 μl of 5 mg/ml goat anti-rat IgG (Cappel Laboratories, Inc., Cochranville, PA) was added and incubation was continued at room temperature for 4 h and then overnight at 4 °C. Precipitates were recovered by centrifugation in a Microfuge and washed with phosphate buffer containing 10 mg/ml of bovine serum albumin and 0.1% Tween 20.

RESULTS

In preliminary experiments we observed that fibroblasts which are not confluent and those which have only become confluent did not synthesize detectable amounts of type V collagen; significant amounts were made only after the cells had remained confluent for 7 or more days. Thereafter, synthesis increased with increasing time in culture for up to 15 days then remained the same until 20 days (data not shown). Whereas the majority of type I and III collagens was secreted into the medium (62–79% and 84–97%, respectively), the presence of type V was restricted to the cell layer, and very little was present in the culture medium (data not shown). The radioactivity in α1(V) and α2(V) chains represented 0.2–0.5% of the total present in cells plus medium; this amount was greater by several-fold when labeling was carried out in the presence of 10% fetal calf serum (see below). Therefore, for most of the studies described here, cells were labeled after 15 days in culture in the presence of 10% serum, and both medium- and cell-associated collagens were combined and processed together.

Characterization of Type V Collagen Chains—For this purpose, labeled proteins were subjected to limited pepsin digestion, and collagens were fractionated on a DEAE-cellulose column at 15 °C. Initially separation was attempted with a 20–300 mM NaCl gradient; however, due to inefficient separation, a stepwise elution procedure was developed (Fig. 1); 65 ± 12% (n = 21) of the loaded radioactivity was recovered in fractions I, II, and III, and no additional radioactive material was recovered by further washing with 1 mM NaCl and 0.4 mM NaOH. Electrophoresis on 5% sodium dodecyl sulfate-polyacrylamide gels showed that fraction I (breakthrough peak), which contained approximately 1–7% of the loaded radioactivity, did not contain collagen chains (Fig. 1, inset, I). Fraction II, which was eluted by 0.11 M NaCl, contained of radioactive proteins, labeled cell and medium proteins containing proteinase inhibitors were dialyzed versus 100 mM NaH2PO4, 150 mM NaCl buffer, pH 7.2, and then treated with 100 μl of a 1:10 diluted antiserum for 1 h at room temperature. Then 100 μl of 5 mg/ml goat anti-rat IgG (Cappel Laboratories, Inc., Cochranville, PA) was added and incubation was continued at room temperature for 4 h and then overnight at 4 °C. Precipitates were recovered by centrifugation in a Microfuge and washed with phosphate buffer containing 10 mg/ml of bovine serum albumin and 0.1% Tween 20.
products were separated on 8% gels. The migration of standard chains of types I and V collagens are indicated.

Phoretic migration similar to the represent the respective bands of Fig. 1, fraction I, and standard types I and V collagens. Characterization of these collagens has been described previously (26) and therefore is not elaborated upon here. Fraction III, the 0.25 M eluate, contained four bands (a-d, Fig. 1, inset, III). These proteins had electrophoretic migration similar to the α chains of types I and V collagens. No other α chains were detected, and the ratio of α/β and α/γ was 2.0. They were characterized as follows. In the first experiment, cells were labeled with [14C]lysine and the extent of lysine hydroxylation in each of the four bands was determined as described under “Materials and Methods.”

The proteins migrating similar to the al(I), a2(I), and the disulfide bonded α and β chains were detected, and the ratio of α/β and α/γ was 2.0. They were characterized as follows. In the first experiment, cells were labeled with [14C]lysine and the extent of lysine hydroxylation in each of the four bands was determined as described under “Materials and Methods.” From Table I it is seen that values for bands a and b are greater than those for c and d, and that values for a and b and c and d resembled α1 and α2 chains of type VI and V collagens, respectively. In the second experiment, fraction III was subjected to digestion with human fibroblast collagenase, and degradation products were separated on 8% polyacrylamide slab gels. Fraction II was treated similarly for a positive control, and it caused the removal of α1(I), α2(I), and α1(III) chains, and the appearance of new bands at locations expected for TCα and TCβ peptides corresponding to Mr = 75,000 and 25,000, respectively (Fig. 2, II). In fraction III, bands c and d behaved in a similar fashion; however, bands a and b remained unaffected, indicating that collagen composed of these α chains is resistant to mammalian collagenase (Fig. 2, III). In the third experiment, fraction III was first separated on 5% gels, and the four bands obtained were digested with CNBr. Peptides formed were then separated on 12.5% gels. The resulting fluorogram was compared to a similar run for the nonradioactive α chains of type I and V collagens, but stained with Coomassie blue. From Fig. 3 it is seen that peptide patterns for bands a, b, c, and d are identical, respectively, to those of α1 and α2 chains of types VI and I collagens.

Characterization of Procollagen(V) Chains—For these studies labeled proteins were taken in buffer containing enzyme inhibitors, precipitated with 50% (NH4)2SO4, and then separated by DEAE-cellulose chromatography at 4°C. Separation was initiated carried out by a 0-200 mM NaCl gradient. However, satisfactory separation of procollagen(V) could not be achieved from the relatively high amounts of procollagen(I). Therefore, a stepwise elution procedure was developed (see “Materials and Methods”). The column was loaded and then eluted in sequence with buffer (fraction I), 0.13 M NaCl (fraction II), and 1.0 M NaCl (fraction III) (figure not shown). Further elution of the column with 0.5 M HCl, 6 M urea recovered <0.7% of radioactivity and the eluted material after pepsin digestion yielded α1(I) and α2(I) (data not shown). Fraction I contained processed α chains and noncollagenous material (data not shown; Ref. 26), whereas fraction II contained precursor α chains of type I and III collagens, and the latter yielded type I and III α chains after pepsin treatment (Fig. 4, a-d). Characterization of these proteins has been described previously (26); therefore, they are not discussed further. Fraction III contained 6-9% of loaded radioactivity, and electrophoresis under nonreducing conditions revealed the presence of two major bands near the origin and at least four other faster migrating bands (Fig. 4f). Prior reduction with MSH removed a major band near the origin, intensified “a” and gave rise to a minor band between u and v; other bands were not affected (Fig. 4e). All these proteins were removed by digestion with bacterial collagenase (Fig. 4h). After pepsin digestion, α1(V) and α2(V) chains were the predominant species (α1/α2 ratio 2.0), and no type I α chains were present (Fig. 4g). Thus, the collagen components present in fraction III appear to be type V. In order to confirm this

### Table I

| Protein band | Hyl | Lys | Hydroxylation
|--------------|-----|-----|----------------
| a            | 18.7| 10.2| 64.7          |
| b            | 4.2 | 5.3 | 44.2          |
| c            | 3.4 | 11.2| 23.3          |
| d            | 3.2 | 7.9 | 28.8          |
| α1(V)        | 34  | 18  | 65.4          |
| α2(V)        | 22  | 14  | 61.1          |
| α1(I)        | 6-14| 23-32| 13.5-37.8    |
| α2(I)        | 17  | 23  | 42.5          |

*Counts/min Hyl/counts/min (Lys + Hyl) × 100.

*Residues/1000, from Ref. 27.

**Fig. 2.** Susceptibility of fraction II and III proteins from Fig. 1 to human fibroblast collagenase. Samples were desalted by dialysis, lyophilized, and divided into two equal halves. One half was incubated with the enzyme as described under “Materials and Methods” (+), and the other remained untreated (−). The reaction products were separated on 8% gels. The migration of standard α chains of types I and V collagens are indicated. TCα and TCβ represent NH2- and COOH-terminal products of the enzyme (Mr = 75,000 and Mr = 25,000 pieces), respectively. a, b, c, and d represent the respective bands of Fig. 1, fraction III.

**Fig. 3.** Sodium dodecyl sulfate-polyacrylamide gel electrophoresis of CNBr-digested α chains derived from fraction III, Fig. 1, and standard types I and V collagens. The proteins were first separated on 5% gel slabs. α chains of the radioactive proteins were located by fluorography (a-d), and the standard collagens by Coomassie blue staining (e-h). The bands were cut, digested with CNBr, layered over a 12.5% gel, and electrophoresed as described under “Materials and Methods.” a, b, c, and d represent patterns for the respective bands in the Fig. 1 inset. e, α1(V); f, α2(V); g, α1(I); h, α2(I). Peptides derived from type I collagen chains are identified.
Biosynthesis and Regulation of Type V Collagen

Fig. 4. Analysis of procollagen fractions II and III (0.13 M and 1.0 M NaCl elutes from the DEAE-cellulose column) by 5% polyacrylamide gel electrophoresis. Radioactive proteins from each fraction were divided into equal portions and subjected to different treatments. "i" was from a separate experiment. a-d, fraction II; e-i, fraction III. a and e, reduced; b and f, untreated; c and g, digested with 100 μg of pepsin at 15 °C for 6 h; d and h, treated with bacterial collagenase for 4 h at 37 °C, i, antibody precipitate. d and h were exposed for 2 weeks, and i was exposed for 34 days. All other patterns were obtained after 47 h of exposure.

Fig. 5. CNBr peptide patterns of radioactive proteins of fraction III from Fig. 4e. The digestion and separation were carried out as described for Fig. 3. p-u represent patterns for respective bands identified in Fig. 4e.

Fig. 6. Effect of serum on type V collagen synthesis. Cells were labeled in the presence or absence of 10% fetal calf serum. Proteins synthesized were subjected to limited pepsin digestion, followed by DEAE-cellulose chromatography as described in the legend to Fig. 1. Samples were electrophoresed without reduction. a-c, -serum; d-f, + serum; a and d, fraction I; b and e, fraction II; c and f, fraction III. The mobilities of α chains of type V are indicated by thick arrows and of type I by thin arrows.

Conclusion and to characterize the individual bands, they were subjected to CNBr digestion followed by electrophoresis on 12.5% gels. From Fig. 5 it is seen that the peptide patterns fall into two groups; p, q, r, and s are similar to each other, as are t, u, and v. When these patterns are compared with those obtained for α1(V) and α2(V) chains in Fig. 3, e and f, it is observed that peptide maps of p, q, r, and s resemble α1(V), and t, u, and v are similar to α2(V). From five separate experiments, the molecular weights of bands p, q, r, s, t, u, and v were calculated, based on collagen standards, to be 370,000 ± 10,000, 239,000 ± 6,000, 219,000 ± 15,000, 198,000 ± 10,000, 174,000 ± 12,000, 157,000 ± 10,000, and 132,000 ± 12,000, respectively. Immune precipitates obtained using type V antibody on electrophoresis revealed the presence of three protein bands, one of Mf = 372,000 remaining near the origin, and two others of Mf = 282,000 and 198,000 (Fig. 4i). However, the pattern obtained under reducing conditions was similar to Fig. 4e, and after limited pepsin digestion, only two proteins migrating with α1(V) and α2(V) chains were observed (not shown). Thus, these data indicate that the procollagen preparations contain two groups of proteins which are related to α1(V) and α2(V), respectively.

Modulation of Type V and III Synthesis—We have reported previously that labeling fibroblasts in the presence of 10% fetal calf serum causes a reduction in the proportion of type III collagen synthesis (32). In the present study it was observed that in the presence of serum type V collagen synthesis was increased, and the increase was 3- to 6-fold in different experiments (Fig. 6 and Table II). In order to investigate whether the changes in the synthesis of type III and V
TABLE II
Synthesis of types I, III, and V collagens by human gingival fibroblasts when labeled in the presence or absence of serum

| Serum | I  | III | V  | % total |
|-------|----|-----|----|--------|
|       | cpm x 10^3 |     |     |        |
| -     | 533.5 | 34.7 | 2.7 | 94.4   | 6.1  | 0.5 |
| +     | 697.7 | 20.3 | 17.9| 94.0   | 3.2  | 2.8 |

Fig. 7. Effect of serum concentration on synthesis of type V and III collagens by human gingival fibroblasts. —, radioactivity; ——, per cent of total (I + III + V); O—O, type V; •—•, type III.

TABLE III
Synthesis of collagens types V and III by human gingival fibroblasts labeled with platelet-poor and platelet-rich human sera

| Serum            | V  | III | % total collagens* |
|------------------|----|-----|-------------------|
|                  | cpm x 10^3 |     | V  | III |
| Platelet-poor    | 8.7 | 33.3| 1.2 | 5.8 |
| Platelet-rich    | 18.7| 14.5| 2.8 | 2.2 |

* (I + III + V).

We have shown that human gingival fibroblasts synthesize a collagens protein comprised of α chains, the electrophoretic mobilities of which are similar to those of α1(V) and α2(V) chains. This protein was shown to be type V by its resistance to digestion by mammalian collagenase, by the higher degree of lysine hydroxylation of the α chains, and by their CNBr peptide maps (1, 3, 14, 30).

Pepsin extracts of placenta, gingiva, and other tissues contain α1, α2, and α3 chains (14–16, 27), and it is not clear whether all these proteins are constituents of type V collagen. However, gingival fibroblast type V collagen fractions obtained by ion exchange chromatography and pepsin digests of procollagen (V) preparations and antibody precipitates contained only α1(V) and α2(V) chains with a ratio of 2:1. Even though a radioactive protein with electrophoretic migration similar to the α3 chain was present in 0.7–1.2 M NaCl fractions of pepsin digests, and occasionally in fraction II of the DEAE-cellulose column eluates, it was not detected in the type V collagen or procollagen fractions, or in antibody precipitates. Therefore, we conclude that type V collagen of gingiva has the chain composition (α1)α2, and that the “α3” chain described previously in the gingival tissue (27) is a contaminant and not a constituent of type V. Our studies do not rule out the possibility of a separate (α1)(α2)(α3) molecule, even though such a molecule would have chromatographic properties similar to the (α1)α2 species.

A portion of type I collagen always co-eluted with type V in fraction III from the DEAE-cellulose columns. Even extensive washing of the columns failed to remove this type I from V (Fig. 1). That the co-eluent was indeed type I was confirmed by electrophoretic migration, α1/α2 ratio, conversion to TCA* and TC5 by mammalian collagenase, and finally by the CNBr peptide pattern. However, the lysines of the α1 and α2 chains in fraction III were hydroxylated to a lesser extent than the respective chains of fraction II (23% and 29% versus 55% and 50%, respectively). Thus, one reason for the difference in the elution behavior between the two type I species may be differences in their lysine hydroxylation (35) and possibly in glycosylation. The reason for the presence of two type I species which differ in their lysine hydroxylation is not clear, although it may be caused by one or more of the nutritional and growth factors present in serum.

The DEAE-cellulose purified procollagen fraction contained at least seven proteins ranging in molecular size from

---

* The abbreviation used is: PDGF, platelet-derived growth factor (human).
132,000 to 370,000; all of these are apparently related to type V collagen, since after digestion by papain only α1 and α2 chains of type V collagen were present (Fig. 4f). Proteins p, r, and s migrated faster under nonreducing than reducing conditions, indicating the presence of interchain disulfide loops (18, 19, 21). Reduction did not induce major changes in pattern except for the possible conversion of the major band near the origin to "r," and the appearance of a minor band between u and v (Fig. 4, e and f). The latter’s CNBr peptide pattern was similar to those of t, u, and v (not shown). From this observation and from the CNBr peptide maps, it can be concluded that a portion of the α1(V) and α2(V) chains are linked by disulfide bonds (19), and that p, q, r, and s, and t, u, and v represent α1(V) and α2(V) chains, respectively, at various processing stages. Band "p" stayed near the origin even after reduction; it had a Mr = 370,000 and a CNBr peptide pattern identical to those of p, q, r, and s, and similar to α1(V), and there was no indication of the presence of α2(V) in it. Thus, it is likely that band p represents the nascent unprocessed proα1(V) chains, or alternatively, a dimer of 188,000 species, although the nature of their association is not clear. Our results show that the α1(V) and α2(V) chains have at least three proteins each at various stages of processing, and the total number of intermediates detected is greater than those reported for chick embryo crop, tendon cells, and A204 rhabdomyosarcoma cells (18, 19, 21). The sizes of unprocessed proα1(V) and proα2(V) have been reported to be 220,000 and 159,000, respectively (21). These proteins were observed in our experiments, but larger molecules with Mr = 239,000 and 174,000 were also present, indicating that sizes of proα1(V) and proα2(V) elaborated by gingival cells are greater than those reported in other cultures. The Mr of proα1(V) may be still larger because the reduced procollagen fraction contained a minor protein band migrating with Mr = 296,000 (Fig. 4e) which had a CNBr pattern similar to α1(V) (data not shown). Pulse-chase experiments to confirm these conclusions were not possible because of low counts during short pulse periods. Bands s and v (Mr = 198,000 and 132,000) appear to be the final products of the α1 and α2 chain processing since smaller molecules were not observed. The value for α1 agrees with 190,000 reported for rhabdomyosarcoma cells, but the gincival α2(V) appears to be smaller (132,000 versus 150,000; Ref. 21).

Normal gingiva contains about 1% type V collagen (24), and this value parallels the proportion of type V made by cultures of gingival fibroblasts. Previous publications have shown that cell density, serum concentration, and epidermal growth factor affect the amount of type III collagen made by fibroblasts (32, 36, 37). Our present data shows that cell density and PDGF regulate type V production and that there is a reciprocal relationship between synthesis of types III and V. PDGF is effective even in the absence of serum, indicating that it may be the major serum factor responsible for modulating the synthesis of these collagens. The mechanism by which collagen synthesis is regulated remains obscure.

In chronically inflamed gingiva, and in certain other diseases such as atherosclerotic aorta wall, the proportion of type V collagen is enhanced greatly (22–25). One feature these seemingly disparate diseases have in common is the exposure of resident tissue fibroblasts and muscle cells to plasma components such as PDGF which they normally do not encounter (33). Our experiments indicate that factors such as PDGF may play a significant role in modifying collagen composition of tissues under pathological conditions through interaction with cells responsible for collagen synthesis.

Acknowledgments—We gratefully acknowledge the gift of human fibroblast collagenase by Dr. Eugene Bauer and of PDGF by Drs. Elaine Raines and Russell Ross. We wish to thank D. F. Meyers and H. P. Peters for technical help provided, and Joan Hiltner and Thea Heinz for manuscript preparation.

REFERENCES

1. Bornstein, P., and Sage, H. (1980) Annu. Rev. Biochem. 49, 957–1003
2. Burgess, R. E., El Adli, F. A., Kaitila, I. I., and Hollister, D. W. (1976) Proc. Natl. Acad. Sci. U. S. A. 73, 2579–2583
3. Rhodes, R. K., and Miller, E. J. (1978) Biochemistry 17, 3442–3448
4. Madri, J. A., and Furthmayr, H. (1979) Am. J. Pathol. 94, 323–330
5. Roll, F. J., Madri, J. A., Albert, J., and Furthmayr, H. (1980) J. Cell Biol. 85, 597–616
6. Sano, J., Fujisawa, S., Sat0, S., Ishizak0, M., Sigisak0, Y., Yajima, G., and Nagai, Y. (1981) Biomed. Res. 20–29
7. Chiang, T. M., Mainardi, C. L., Seyer, J. M., and Kang, A. J. (1986) J. Lab. Clin. Med. 98, 99–107
8. Stenn, K. S., Madri, J. A., and Poll, F. J. (1979) Nature (Lond.) 277, 229–232
9. Kleinman, H. K., Klebe, R. J., and Martin, G. R. (1981) J. Cell Biol. 88, 473–485
10. Grotendorst, G. R., Seppa, H. E. J., Kleinman, H. K., and Martin, G. R. (1981) Proc. Natl. Acad. Sci. U. S. A. 78, 3669–3672
11. Martinez-Hernandez, A., Gay, S., and Miller, E. J. (1982) J. Cell Biol. 92, 343–349
12. Linsenmayer, T. F., Fitch, J. M., Schmid, T. M., Zak, N. B., Gibney, E., Sanderson, R. D., and Mayne, R. (1983) J. Cell Biol. 96, 124–132
13. Day, Z., Macek, K., and Adam, M. (1979) Biochem. Biophys. Res. Commun. 89, 627–634
14. Sage, H., and Bornstein, P. (1979) Biochemistry 18, 3815–3822
15. Sage, H., Pritzl, P., and Bornstein, P. (1981) Biochemistry 20, 3778–3784
16. Brown, R. A., and Weiss, J. B. (1979) FEBS Lett. 106, 71–75
17. Heras0n, M. A., Mitchell, W. M., Rhodes, R. K., Kesrina, T. F., Gay, R., and Miller, E. J. (1980) Proc. Natl. Acad. Sci. U. S. A. 77, 5026–5021
18. Kumamoto, C. A., and Fessler, J. H. (1981) J. Biol. Chem. 256, 7053–7065
19. Fessler, L. J., Robinson, W. J., and Fessler, J. H. (1981) J. Biol. Chem. 256, 9646–9651
20. Bäschiger, H. P., Doege, K. J., Petschek, J. P., Fessler, L. I., and Fessler, J. H. (1982) J. Biol. Chem. 257, 14590–14592
21. Altitalo, K., Myllyla, R., Sage, H., Fitch, P., Valeri, A., and Bornstein, P. (1982) J. Biol. Chem. 257, 9026–9024
22. Ooshima, A. (1981) Science (Wash. D. C.) 213, 466–468
23. Morton, L. F., and Barnes, M. J. (1982) Atherosclerosis 42, 41–51
24. Narayanan, A. S., Engel, L. D., and Page, R. C. (1983) Collagen Rel. Res. 3, 233–239
25. Barsky, S. H., Rao, C. N., Gottendorst, G. R., and Liotta, L. A. (1982) Am. J. Pathol. 108, 276–283
26. Narayanan, A. S., and Page, R. C. (1976) J. Biol. Chem. 251, 5464–5471
27. Narayanan, A. S., Page, R. C., and Meyers, D. F. (1980) Biochemistry 19, 5037–5043
28. Smith, B. D., Byers, P. H., and Martin, G. R. (1972) Proc. Natl. Acad. Sci. U. S. A. 69, 3260–3262
29. Barsh, G. S., Peterson, K. E., and Byers, P. H. (1981) Collagen Rel. Res. 1, 534–548
30. Welgus, H. G., Jeffrey, J. J., and Eisen, A. Z. (1981) J. Biol. Chem. 256, 9511–9515
31. Nowack, H., Gay, S., Wick, G., Becker, U., and Timpl, R. (1976) J. Immunol. Methods 12, 117–124
32. Narayanan, A. S., and Page, R. C. (1977) FEBS Lett. 80, 221–224
33. Ross, R., and Vogt, A. (1978) Cell 14, 203–210
34. Rutherford, R. B., and Ross, R. (1976) J. Cell Biol. 69, 196–203
35. Trelstad, R. L., Kang, A. H., Toole, B. P., and Gross, J. (1972) J. Biol. Chem. 247, 6469–6473
36. Abe, S., Steinmann, B. U., Wahl, L. M., and Martin, G. R. (1979) Nature (Lond.) 270, 442–444
37. Steinmann, B. U., Abe, S., and Martin, G. R. (1982) Collagen Rel. Res. 2, 185–195

Downloaded from http://www.jbc.org/ by guest on March 22, 2020
Biosynthesis and regulation of type V collagen in diploid human fibroblasts.
A S Narayanan and R C Page

J. Biol. Chem. 1983, 258:11694-11699.

Access the most updated version of this article at http://www.jbc.org/content/258/19/11694

Alerts:
• When this article is cited
• When a correction for this article is posted

Click here to choose from all of JBC's e-mail alerts

This article cites 0 references, 0 of which can be accessed free at http://www.jbc.org/content/258/19/11694.full.html#ref-list-1