

# Enzymatic synthesis of a blood group A related, difucosyl heptaglycosylceramide with a type 2 carbohydrate chain

Bo E. Samuelsson

Department of Medical Biochemistry, University of Göteborg, Box 33031, S-400 33 Göteborg, and Regional Blood Bank, Sahlgren's University Hospital, S-413 45 Göteborg, Sweden

Received 22 November 1982; revision received 3 January 1983

The presence of an  $\alpha 1 \rightarrow 3$  fucosyltransferase in the serum of an  $A_1Rh(-) Le(a-b+) Fy(a-b+) Jk(a+b+) K(-) M(-) N(+) S(-) s(+) P_1(+)$  human secretor was shown, capable of converting a blood group A active hexaglycosylceramide with a type 2 carbohydrate chain into the corresponding difucosyl compound under in vitro conditions.

<i>Glycolipid</i>	<i>Fucolipid</i>	<i>Blood group A</i>	<i>Glycosyltransferase</i>
	<i>Fucosyltransferase</i>	<i>GDP-fucose</i>	

## 1. INTRODUCTION

The carbohydrate structures in glycolipids, glycoproteins and oligosaccharides that confer A, B, H and Lewis blood group specificities on these molecules are built up by sequential action of a series of glycosyltransferases determined by genes at several different loci. The blood group genes at the ABO, H and Lewis loci are concerned only in the final stages of the biosynthesis of the carbohydrate structures [1]. The blood group A active structures terminate with *N*-acetyl-D-galactosamine in an  $\alpha$ -linkage to the C-3 position of a subterminal  $\beta$ -D-galactosyl unit which is also substituted at the C-2 position with L-fucose by the blood group H glycosyltransferase. In these oligosaccharides the  $\beta$ -D-galactosyl residues may be joined [1] by either a  $1 \rightarrow 3$  (type 1 chain) or a  $1 \rightarrow 4$  (type 2 chain) linkage to the following *N*-acetyl-D-glucosamine (table 1).

The Lewis gene controls a glycosyltransferase which adds L-fucose on the 4 position of the *N*-acetyl-D-glucosamine and therefore the  $Le^a$  and

$Le^b$  active structures are based only on type 1 chains. The corresponding type 2 chain isomers have also been isolated but lack serologic  $Le^a$  or  $Le^b$  activity. The gene that controls a glycosyltransferase which adds L-fucose on the 3 position of the *N*-acetyl-D-glucosamine in these compounds appears to have a high frequency [2-4]. One unique exception has however been described [5]. Carbohydrate determinants related to blood group A, but with two fucosyl substituents, have been isolated from ovarian cyst glycoproteins and human urine oligosaccharides [6,7] and important data concerning their biosynthesis have been presented [8,9]. Blood group A difucosyl heptaglycosylceramides (glycolipid) have been identified and characterized from various sources [10] and nothing is so far known about their biosynthesis. The aim of the present investigation was to study the biosynthesis of these compounds.

## 2. MATERIALS AND METHODS

Serum was obtained from an  $A_1Rh(-) Le(a-b+) Fy(a-b+) Jk(a+b+) K(-) M(-) N(+) S(-) s(+) P_1(+)$  secretor and concentrated 4 times using a 'Minicon' concentrator at  $+4^\circ C$ .

Part of this work was presented at the 16th Congress of the International Society of Blood Transfusion in Montreal, August 1980

Table 1  
Some carbohydrate chain endings of relevance to the text

GalNAc $\alpha$ 1 $\rightarrow$ 3Gal $\beta$ 1 $\rightarrow$ 3GlcNAc- 2 ↑ Fuc $\alpha$ 1	Blood-group A determinant type 1 chain
GalNAc $\alpha$ 1 $\rightarrow$ 3Gal $\beta$ 1 $\rightarrow$ 4GlcNAc- 2 ↑ Fuc $\alpha$ 1	Blood-group A determinant type 2 chain
Gal $\beta$ 1 $\rightarrow$ 3GlcNAc- 4 ↑ Fuc $\alpha$ 1	Le <sup>a</sup> determinant type 1 chain
Gal $\beta$ 1 $\rightarrow$ 4GlcNAc- 3 ↑ Fuc $\alpha$ 1	X determinant type 2 chain [23]
Gal $\beta$ 1 $\rightarrow$ 3GlcNAc- 2            4 ↑            ↑ Fuc $\alpha$ 1      Fuc $\alpha$ 1	Le <sup>b</sup> determinant type 1 chain
Gal $\beta$ 1 $\rightarrow$ 4GlcNAc- 2            3 ↑            ↑ Fuc $\alpha$ 1      Fuc $\alpha$ 1	Y determinant type 2 chain [23]
GalNAc $\alpha$ 1 $\rightarrow$ 3Gal $\beta$ 1 $\rightarrow$ 3GlcNAc- 2            4 ↑            ↑ Fuc $\alpha$ 1      Fuc $\alpha$ 1	Blood-group A, difucosyl determinant type 1 chain
GalNAc $\alpha$ 1 $\rightarrow$ 3Gal $\beta$ 1 $\rightarrow$ 4GlcNAc- 2            3 ↑            ↑ Fuc $\alpha$ 1      Fuc $\alpha$ 1	Blood-group A, difucosyl determinant type 2 chain

The concentrated serum sample was used immediately or stored at  $-20^{\circ}\text{C}$  before use. The serum preparation was incubated under essentially the same conditions as were described [4]. The incubation mixture contained in a final volume of  $100\ \mu\text{l}$ :  $60\ \mu\text{l}$  of the serum preparation, about 130000 cpm of GDP- $[^{14}\text{C}]$ fuco (Radiochemical Centre, Amersham),  $2.5\ \mu\text{mol}$  Tris-HCl buffer (pH 7.5),  $1\ \mu\text{mol}$   $\text{NaN}_3$ ,  $0.75\ \mu\text{mol}$   $\text{MgCl}_2$ ,  $1\ \mu\text{mol}$  ATP, Triton X-100 0.1% and precursor glycolipid 50–200  $\mu\text{g}$ . The incubation mixture was kept at  $37^{\circ}\text{C}$  for 48 h under continuous gentle agitation.

The incubation mixture was extracted sequentially by 5 ml of methanol, chloroform/methanol 2:1 v/v, chloroform/methanol 1:2 v/v and methanol at  $70^{\circ}\text{C}$ . The combined extracts were evaporated to dryness and subjected to mild alkaline hydrolysis and dialysis. Non-acid glycosphingolipids were prepared by a combina-

tion of silicic acid chromatography and DEAE chromatography essentially as described [11].

The total non-acid glycosphingolipid fraction prepared from the incubation mixtures was analysed by thin-layer chromatography as native and acetylated derivatives.

Thin-layer chromatography was performed on HPTLC plates (Merck). For autoradiographic detection Ilford 25GP X-ray film was used. After exposure the film was developed using Ilford Phen-X, X-ray developer. Determination of radioactivity was also done of an aliquot of the fraction in a liquid scintillation spectrometer (Packard) after evaporation of the organic solvent and addition of 10 ml of a solution containing 3 g PPO, 75 mg POPOP, 500 ml toluene and 250 ml Triton X-100. For detection of non-radioactive glycolipids the anisaldehyde reagent was used [12]. The blood group A active hexaglycosylceramide

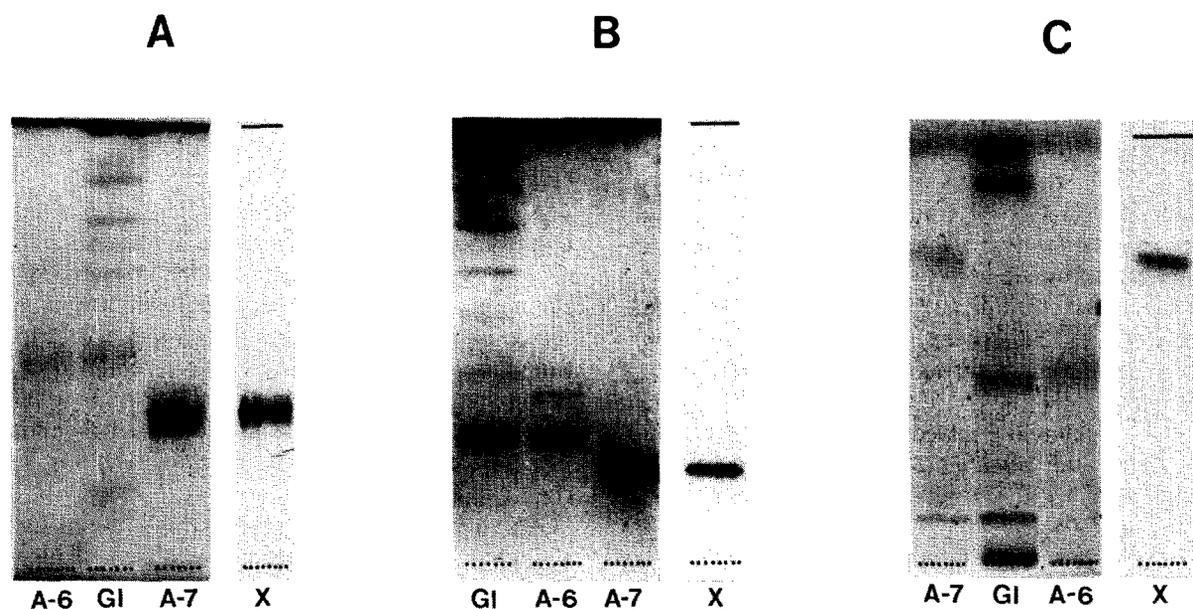


Fig.1. Thin-layer chromatograms showing the non-acid glycosphingolipid fraction  $Gf$ , prepared from an incubation mixture that contained a blood group A active hexaglycosylceramide with a type 2 carbohydrate chain isolated from dog intestine, GDP- $[^{14}\text{C}]$ fuco and serum from an  $A_1\text{Rh}(-)\text{Le}(a-b+)$  secretor, analysed as native derivatives in two different solvents, fig.1A and B, and as acetylated derivatives in one solvent, fig.1C. The precursor glycolipid, A-6 (blood group A active hexaglycosylceramide with a type 2 chain), and the expected product, A-7 (blood group A similar difucosyl heptaglycosylceramide with a type 2 carbohydrate chain isolated from dog intestine) are also analysed as references. The solvent systems for the thin-layer plates were as follows: (A) chloroform/methanol/ $\text{NH}_3$  (conc.), 40:40:12, by vol.; (B) chloroform/methanol/water, 60:35:8, by vol.; (C) chloroform/methanol, 95:5, by vol. After development the thin-layer plates were covered with an X-ray film and left in the dark for 4 days. Lane X in A–C above shows the result of the autoradiographic detection of lane  $Gf$  in each case. After autoradiography the plates were visualized with the anisaldehyde reagent [12].

used as a precursor and the reference heptaglycosylceramide were both isolated from dog intestine and shown to have the following structures:  $\text{GalNAc}\alpha 1 \rightarrow 3\text{Gal}(2 \leftarrow 1\alpha\text{Fuc})\beta 1 \rightarrow 4\text{GlcNAc}\beta 1 \rightarrow 3\text{Gal}\beta 1 \rightarrow 4\text{Glc}\beta 1 \rightarrow 1\text{Ceramide}$  [13,14] and  $\text{GalNAc}\alpha 1 \rightarrow 3\text{Gal}(2 \leftarrow 1\alpha\text{Fuc})\beta 1 \rightarrow 4\text{GlcNAc}(3 \leftarrow 1\alpha\text{Fuc})\beta 1 \rightarrow 3\text{Gal}\beta 1 \rightarrow 4\text{Glc}\beta 1 \rightarrow 1\text{Ceramide}$  ([15,16] and McKibbin et al. unpublished). The ceramide composition was hydroxy fatty acids in combination with about equal amounts of the sphingosine base: t18:0 and d18:1. The ceramide composition was almost identical between the two glycolipids.

### 3. RESULTS

Figure 1A–C show the thin-layer chromatogram of the non-acid glycosphingolipid fraction, *G<sub>l</sub>*, prepared from an incubation mixture that contained a blood group A active hexaglycosylceramide with a type 2 carbohydrate chain isolated from dog intestine, GDP-[<sup>14</sup>C]fucose and serum from an A<sub>1</sub>Rh(–) Le(a–b+) secretor, analysed as native derivatives in two different solvents, fig.1A and B, and as acetylated derivatives in one solvent, fig.1C. The precursor glycolipid, A-6 (blood group A active hexaglycosylceramide, type 2 chain), and the expected product, A-7 (the corresponding heptaglycosylceramide with two fucose residues and a terminal hexosamine, type 2 chain), are also analysed as references. Lane X shows the autoradiographic detection of lane *G<sub>l</sub>* of the thin-layer plate.

The non-acid glycosphingolipid fraction prepared after incubation, *G<sub>l</sub>*, contained 2400 counts/min (130000 cpm GDP-[<sup>14</sup>C]fucose was added initially).

As can be seen the radioactive spot on the autoradiogram has the same *R<sub>F</sub>*-value as the reference glycolipid, A-7, in all solvents used, both as native and as acetylated derivatives.

### 4. DISCUSSION

The preparation of a pure non-acid glycosphingolipid fraction from the incubation mixture is considered important for the interpretation of results. An autoradiogram is obtainable at any preparative stage but the probability of a glycolipid causing the radioactive spot increases

with purity. This concept is not always appreciated.

Identification of the product was based on comparison of the thin-layer chromatographic mobility with a known reference of the expected product. The comparison was made both as native substances and as acetylated derivatives and using different solvent systems. Acetylation of glycosphingolipids has a profound effect on their chromatographic mobility and may also change the order between individual glycosphingolipids [17,18].

The ceramide composition of glycosphingolipids is also known to influence the chromatographic mobility. The partial separation into minor bands on the thin-layer plates, figs.1A–C, is most probably caused by a heterogeneous ceramide as the carbohydrate part is uniform [13–16]. It is therefore considered important to use reference compounds of similar ceramide compositions as the expected product for a safe identification based on thin-layer chromatographic mobility. In the present case both the precursor glycolipid and the reference glycolipid were prepared from the same source and shown to have almost identical ceramide composition [13–16].

Although no structural characterization (mass spectrometry, NMR, degradation) was done on the radioactive product, it appears safe to conclude the presence of an  $\alpha 1 \rightarrow 3$  fucosyltransferase in the serum of a human A, Le(a–b+) secretor (additional typing, see above), capable of converting a blood group A active hexaglycosylceramide with a type 2 carbohydrate chain into the corresponding difucosyl compound under in vitro conditions, see fig.2.

An alternative pathway would be from an Le<sup>b</sup>-similar hexaglycosylceramide with type 2 chain (table 1). However, a highly purified porcine blood group A specific *N*-acetylgalactosaminyltransferase [9] failed to work on an Le<sup>b</sup>-active hexaglycosylceramide (type 1 chain). Unfortunately, the type 2 chain isomer was not tested.

The present knowledge about  $\text{Fuca}1 \rightarrow 3$  transferase(s) is complex. Recently [19]  $\text{Fuca}1 \rightarrow 3$  and  $\text{Fuca}1 \rightarrow 4$  transferases were co-purified over 500000-fold from human milk, suggesting that both enzymatic activities reside in a single enzyme and thus obscuring the Lewis genetics (Le gene codes for a  $\text{Fuca}1 \rightarrow 4$  transferase). Further-

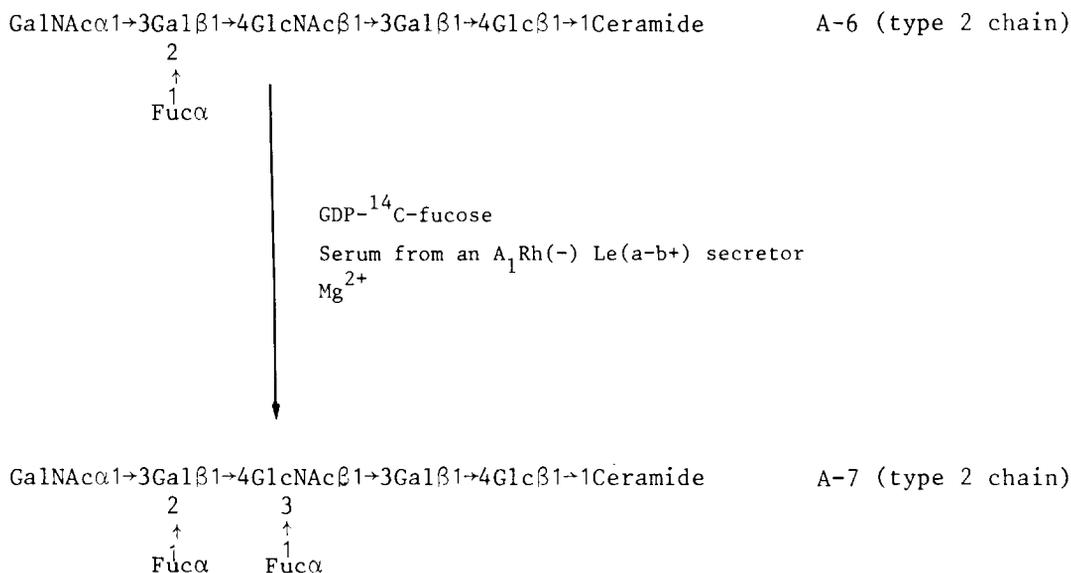


Fig.2. Proposed biosynthetic scheme.

more, evidence has been presented for the presence of two Fuc $\alpha$ 1  $\rightarrow$  3 transferases in human saliva [20]. Both enzymes were shown capable of transferring L-fucose to the C-3 position of *N*-acetyl-D-glucosamine while only one had capacity of transferring L-fucose to C-3 of D-glucose and was furthermore dependent on the Le gene. If the enzymatic activity described in this paper is due to an additional enzyme species in a Fuc $\alpha$ 1  $\rightarrow$  3 transferase family or is due to a common Fuc $\alpha$ 1  $\rightarrow$  3 transferase with a limited precursor specificity requires further studies.

The biosynthesized difucosyl heptaglycosylceramide (type 2 chain) has so far not been found on red blood cell membranes [21]. Its type 1 chain isomer, the Siedler antigen, has however been shown to be taken up on red cells from plasma [22]. The site for its biosynthesis is unknown. The biological importance of the described Fuc $\alpha$ 1  $\rightarrow$  3 enzymatic activity remains to be elucidated.

#### ACKNOWLEDGEMENTS

J.M. McKibbin and K.-A. Karlsson are gratefully acknowledged for the gift of samples. The work was supported by grants from the Swedish Medical Research Council (3967 and 6521).

#### REFERENCES

- [1] Watkins, W.M. (1978) Proc. R. Soc. Lond. Ser. B 202, 31-53.
- [2] Chester, M.A. and Watkins, W.M. (1969) Biochem. Biophys. Res. Commun. 34, 835-842.
- [3] Schenkel-Brunner, H., Chester, M.A. and Watkins, W.M. (1972) Eur. J. Biochem. 30, 269-277.
- [4] Pacuszka, T. and Kościelak, J. (1976) Eur. J. Biochem. 64, 499-506.
- [5] Kobata, A. and Ginsburg, V. (1969) J. Biol. Chem. 244, 5496-5502.
- [6] Lloyd, K.O. and Kabat, E.A. (1966) Biochemistry 5, 1489-1501.
- [7] Kobata, A. (1977) in: Glycoconjugates (Horowitz, M.I. and Pigman, W. eds) pp.423-440, Academic Press, New York.
- [8] Kobata, A. and Ginsberg, V. (1970) J. Biol. Chem. 245, 1484-1490.
- [9] Schwyzer, M. and Hill, R.L. (1977) J. Biol. Chem. 252, 2346-2355.
- [10] McKibbin, J.M. (1978) J. Lipid Res. 19, 131-147.
- [11] Breimer, M.E., Hansson, G.C., Karlsson, K.-A. and Leffler, H. (1981) Exp. Cell Res. 135, 1-13.
- [12] Karlsson, K.-A., Samuelsson, B.E. and Steen, G.O. (1973) Biochim. Biophys. Acta 316, 317-335.
- [13] Smith, E.L., McKibbin, J.M., Karlsson, K.-A., Pascher, I. and Samuelsson, B.E. (1975) Biochemistry 14, 2120-2124.

- [14] McKibbin, J.M., Smith, E.L., Månsson, J.-E. and Li, Y.-T. (1977) *Biochemistry* 16, 1223–1228.
- [15] Smith, E.L., McKibbin, J.M., Breimer, M.E., Karlsson, K.-A., Pascher, I. and Samuelsson, B.E. (1975) *Biochim. Biophys. Acta* 398, 84–91.
- [16] Falk, K.-E., Karlsson, K.-A. and Samuelsson, B.E. (1979) *Arch. Biochem. Biophys.* 192, 191–202.
- [17] Karlsson, K.-A. and Larson, G. (1979) *J. Biol. Chem.* 254, 9311–9316.
- [18] Breimer, M.E., Karlsson, K.-A. and Samuelsson, B.E. (1981) *J. Biol. Chem.* 256, 3810–3816.
- [19] Prieels, J.-P., Monnom, D., Dolmans, M., Beyer, T.A. and Hill, R.L. (1981) *J. Biol. Chem.* 256, 10456–10463.
- [20] Johnson, P.H., Yates, A.D. and Watkins, W.M. (1981) *Biochem. Biophys. Res. Commun.* 100, 1611–1618.
- [21] Hakomori, S.-I. (1981) *Seminars in Hematology* 13, 39–62.
- [22] Tilley, C.A., Crookston, M.C., Brown, B.L. and Wherrett, J.R. (1975) *Vox Sang.* 28, 25–33.
- [23] Kobata, A. (1975) *Kagaku* 30, 192.