

Fetal macrosomia related to maternal poorly controlled type 1 diabetes strongly impairs serum lipoprotein concentrations and composition

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Abstract

Aims—To determine the effects of fetal macrosomia related to maternal type 1 diabetes on the lipid transport system.

Methods—Serum lipoprotein concentrations and composition and lecithin:cholesterol acyltransferase (LCAT) activity were investigated in macrosomic newborns (mean birth weight, 4650 g; SEM, 90) and their mothers with poorly controlled type 1 diabetes, in appropriate for gestational age newborns (mean birth weight, 3616 g; SEM, 68) and their mothers with well controlled type 1 diabetes, and macrosomic (mean birth weight, 4555 g; SEM, 86) or appropriate for gestational age (mean birth weight, 3290 g; SEM, 45) newborns and their healthy mothers.

Results—In mothers with well controlled type 1 diabetes, serum lipids, apolipoproteins, and lipoproteins were comparable with those of healthy mothers. Similarly, in their infants, these parameters did not differ from those of appropriate for gestational age newborns. Serum triglyceride, very low density lipoprotein (VLDL), apolipoprotein B100 (apo B100), and high density lipoprotein (HDL) triglyceride concentrations were higher, whereas serum apo A-I and HDL₃ concentrations were lower in mothers with diabetes and poor glycaemic control than in healthy mothers. Their macrosomic newborns had higher concentrations in all serum lipids and lipoproteins, with high apo A-I and apo B100 values compared with appropriate for gestational age newborns. In macrosomic infants of healthy mothers, there were no significant differences in lipoprotein profiles compared with those of appropriate for gestational age infants. LCAT activity was similar in both groups of mothers and newborns.

Conclusion—Poorly controlled maternal type 1 diabetes and fetal macrosomia were associated with lipoprotein abnormalities. Macrosomic lipoprotein profiles related to poor metabolic control of type 1 diabetes appear to have implications for later metabolic diseases.

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Keywords: apolipoproteins; lipids; lipoproteins; lecithin:cholesterol acyltransferase; fetal macrosomia; maternal type 1 diabetes

Macrosomia or fetal obesity (birth weight > 4000 g at term) is a frequent complication of pregnancy in diabetes.¹ Maternal hyperglycaemia leads to fetal hyperglycaemia, which stimulates pancreatic islet cells and produces hyperinsulinaemia.² This intrauterine hyperinsulinaemic state results in increased fat tissue, liver glycogen content, and total body size.²⁻³ Other maternal fuels such as plasma amino acids and lipids are also thought to be contributors to overgrowth.⁴⁻⁷ Disturbances of maternal metabolism are well known factors affecting growth. Because type 1 diabetes mellitus produces changes in maternal metabolic fuels,⁸⁻¹⁰ and because diabetic pregnancy is often associated with macrosomia, the effects of maternal diabetes on lipid metabolism are unclear.

Macrosomic infants of diabetic mothers have been shown to be prone to the development of glucose intolerance, obesity, and diabetes during childhood and adulthood.¹¹⁻¹³ Obesity and diabetes are associated with lipoprotein abnormalities such as high plasma triglyceride (TG) concentrations and low high density lipoprotein (HDL) cholesterol concentrations.¹⁴⁻¹⁵ HDL has been shown to protect against the development of atherosclerosis because of the ability of HDL₃ to mediate reverse cholesterol transport from the cell to the liver.¹⁶ Lecithin:cholesterol acyltransferase (LCAT; EC 2.3.1.43), an enzyme produced in the liver, esterifies free cholesterol of the HDL₃ subclass, converting it into the HDL₂ subfraction.¹⁷ This process enables HDL₃ to accept a greater amount of cholesterol. LCAT influences not only the metabolism of HDL but also that of other lipoproteins.¹⁸ Early studies showed that HDL₂ and HDL₃ cholesterol concentrations and LCAT activity are lower at birth in full term infants than in adults.¹⁹⁻²⁰ We have reported previously that LCAT activity is low in small for gestational age newborns.²¹ However, no information has been provided on HDL subfractions and LCAT activity in the sera of macrosomic infants of diabetic mothers.

There is increasing interest in the importance of lipoprotein metabolism during life and its implications for later cardiovascular diseases.²² Because obesity and hyperinsulinaemia begin early in life in macrosomic infants of mothers with type 1 diabetes,²³ it would be interesting to see whether these infants present "at risk" lipoprotein profiles at birth, which would make them prone to later metabolic diseases.

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Table 1 Maternal characteristics

	Group 1	Group 2	Group 3	Group 4
Number of subjects	20	20	18	30
Age (years)	25.0 (1.5)	24.0 (1.6)	25.0 (1.8)	25.0 (1.3)
BMI (kg/m ²)	22.4 (1.9)	22.1 (1.6)	22.8 (1.7)	21.8 (2.3)
Weight gain (kg)	11.8 (0.8)	9.8 (0.7)	12.0 (0.9)	10.5 (0.6)
Parity	2.0 (1.0)	2.0 (1.0)	2.0 (1.0)	2.0 (1.0)
Hb A1 (%)	8.9 (0.3)*	6.3 (0.4)**	6.0 (0.3)**	5.8 (0.2)**
Glucose (mmol/l)	8.7 (0.4)*	5.2 (0.1)**	4.8 (0.2)**	4.9 (0.2)**
Birth weight (g)	4650 (90)*	3616 (98)**	4555 (86)*	3290 (45)**
Gestational age (weeks)	38.5 (0.3)	39.5 (0.6)	39.0 (0.5)	39.5 (0.8)
Cord insulin (mU/l)	40.02 (1.62)*	12.23 (1.39)**	10.65 (1.09)**	10.38 (1.11)**

Values are mean (SEM).

Group 1, mothers with poorly controlled diabetes and macrosomic newborns.

Group 2, mothers with well controlled diabetes and appropriate for gestational age newborns.

Group 3, healthy mothers with macrosomic newborns.

Group 4, healthy mothers with appropriate for gestational age newborns.

Values within a row with different numbers of asterisks are significantly different, $p < 0.05$.

The purpose of our present investigation was to determine whether lipoprotein metabolism is altered in macrosomic newborns of mothers with poorly controlled type 1 diabetes and, if so, to what extent these abnormalities are related to maternal lipid disturbances.

Material and methods

PATIENTS

The subjects for our study were drawn consecutively from women investigated at the Maternity Hospital of Tlemcen, Algeria. Forty pregnant women with type 1 diabetes whose newborns were macrosomic or appropriate for gestational age at birth, after term deliveries, were selected. Maternal diabetic status was determined by medical history review. Twenty one mothers had White's class B (mean duration of diabetes, 4 years; SEM, 0.6) diabetes, and 19 had White's class C (mean duration of diabetes, 12 years; SEM, 1) diabetes. Table 1 summarises the anthropometric and laboratory characteristics of these mothers. All mothers with diabetes were treated with insulin during pregnancy (multiple injection self administration of short or long acting doses of insulin), but 20 (mothers of macrosomic newborns) were poorly controlled, as shown by their glycosylated haemoglobin concentrations (Hb A1, performed by isolab column chromatography²⁴; interassay coefficient of variation (CV) of 7.2%; normal range of Hb A1 was 4–7%) and their fasting glucose concentrations determined by a glucose oxidase procedure (Beckman glucose analyser; Beckman, Palo Alto, California, USA) with a CV less than 4%, during the last term of pregnancy (table 1). Diabetes in mothers of appropriate for gestational age newborns was considered well controlled, with Hb A1 values close to normal reference values. For comparison, 48 healthy pregnant women whose babies were macrosomic or appropriate for gestational age at term were selected after an oral glucose tolerance test within 48 hours of birth. Only women with a normal glucose tolerance test according to the World Health Organisation (WHO) criteria²⁵ were enrolled as control cases. An attempt was made to match these women with those with diabetes, at least with regard to maternal age, height, parity, gestational age, weight gain during pregnancy, and mode of delivery (table 1). No subjects

were obese or hypertensive. Newborns with malformations or with intrauterine growth retardation were excluded.

The gestational age of all the neonates was ≥ 38 weeks. Gestational age was assessed according to the mother's menstrual history and ultrasonography, and then confirmed by the paediatrician's assessment of the baby's maturity. Newborn weight was obtained immediately after delivery. Macrosomia was defined as a birth weight of ≥ 4000 g at term. The infants belonged to one of the four following groups: (1) Group 1 consisted of 20 pairs of mothers with poorly controlled type 1 diabetes and their macrosomic newborns at term (mean birth weight, 4650 g; SEM, 9). These macrosomic newborns had significantly higher cord serum insulin (measured by radioimmunoassay) values than appropriate for gestational age newborns (table 1). (2) Group 2 comprised 20 pairs of mothers with well controlled type 1 diabetes and their appropriate for gestational age newborns at term (mean birth weight, 3616 g; SEM, 68). (3) Group 3 comprised 18 pairs of healthy mothers and their macrosomic newborns at term (mean birth weight, 4555 g; SEM, 86). In these newborns, insulin concentrations were similar to those found in appropriate for gestational age newborns. (4) Group 4 comprised 30 pairs of healthy mothers and their appropriate for gestational age newborns (mean birth weight, 3290 g; SEM, 45).

We explained the purpose of our study to the mothers and the investigation was carried out with their consent. The experimental protocol was approved by the local human subjects review committee of the University Hospital of Tlemcen, Algeria.

BLOOD SAMPLES

Maternal blood was collected from the arm vein of the mothers within 48 hours of birth under fasting conditions. Cord blood samples were obtained from the umbilical vein immediately after delivery and cutting the umbilical cord. After clotting, sera were separated by centrifugation at 600 \times g and 4°C. An aliquot of serum was preserved with 0.1% disodium EDTA and 0.02% sodium azide to measure and analyse lipoproteins; another part was used to measure LCAT activity.

LABORATORY METHODS

Lipoprotein isolation

Serum lipoprotein fractions were separated by sequential ultracentrifugation (very low density lipoprotein (VLDL), $1.006 < d < 1.019$; low density lipoprotein (LDL), $1.019 < d < 1.063$; HDL₂, $1.063 < d < 1.12$; HDL₃, $1.12 < d < 1.21$ g/ml) in a Beckman ultracentrifuge (model L5-65, 65 Ti rotor), using sodium bromide for density adjustment, according to Havel *et al.*²⁶

Chemical analysis

Triglyceride, total cholesterol, and unesterified cholesterol contents of serum and each lipoprotein fraction were measured by means of a Boehringer kit (Mannheim, Germany), using

Table 2 Serum lipid (mmol/litre), apolipoprotein A-I (apo A-I) and apo B100 (both g/litre) values, and LCAT activity of mothers with diabetes, control mothers, and their newborns

	Mothers				Newborns			
	Group 1	Group 2	Group 3	Group 4	Group 1	Group 2	Group 3	Group 4
Triglycerides	4.25 (0.17)*	2.90 (0.2)**	2.99 (0.20)**	2.60 (0.21)**	1.45 (0.20)*	0.58 (0.12)**	0.80 (0.15)**	0.62 (0.10)**
Phospholipids	3.54 (0.23)	3.69 (0.20)	3.80 (0.16)	3.70 (0.12)	2.50 (0.14)*	1.66 (0.11)**	1.86 (0.14)**	1.75 (0.20)**
Unesterified cholesterol	1.50 (0.10)	1.52 (0.11)	1.64 (0.14)	1.55 (0.14)	1.00 (0.04)*	0.71 (0.03)**	0.72 (0.04)**	0.70 (0.03)**
Cholesteryl esters	5.10 (0.40)	4.98 (0.45)	5.20 (0.51)	4.90 (0.61)	1.30 (0.02)*	1.12 (0.03)**	1.10 (0.02)**	1.08 (0.01)**
Apo A-I	1.10 (0.03)**	1.58 (0.02)*	1.62 (0.05)*	1.60 (0.04)*	0.92 (0.03)*	0.65 (0.0)**	0.70 (0.02)**	0.68 (0.01)**
Apo B100	1.68 (0.04)*	1.20 (0.06)**	1.18 (0.05)**	1.10 (0.06)**	0.50 (0.0)*	0.20 (0.04)**	0.21 (0.06)**	0.18 (0.02)**
LCAT (nmol/ml/h)	269 (48)	270 (55)	275 (67)	252 (56)	160 (41)	123 (52)	133 (43)	110 (50)

Values are means (SEM).

Group 1, mothers with poorly controlled diabetes and macrosomic newborns.

Group 2, mothers with well controlled diabetes and appropriate for gestational age newborns.

Group 3, healthy mothers with macrosomic newborns.

Group 4, healthy mothers with appropriate for gestational age newborns.

Values within a row with different numbers of asterisks are significantly different, $p < 0.05$.

LCAT, lecithin:cholesterol acyltransferase.

enzymatic methods; the interassay CV was in the range of 1.7% to 3.2%. Esterified cholesterol concentrations were obtained by calculating the difference between total cholesterol and unesterified cholesterol values. Total phospholipids were assayed for phosphorus content by the method of Bartlett,²⁷ with an interassay CV of 7%. The total protein contents of each lipoprotein were measured by the method of Lowry *et al*,²⁸ using bovine serum albumin as standard (with an interassay CV of 5.6%). Serum apolipoprotein A-I (apo A-I) and apo B-100 concentrations were measured by immunoelectrophoresis using monoclonal antibodies and ready to use plates (Sebia kit; Hydrigel, Issy Les Moulineaux, France), with an interassay CV of < 4%.

VLDL, HDL₂, and HDL₃ apolipoprotein separation and measurement

After concentration by partial lyophilisation and rapid diethyl/ether delipidation of VLDL, HDL₂, and HDL₃, the apolipoproteins of each lipoprotein fraction were separated by sodium dodecyl sulphate polyacrylamide gel electrophoresis (SDS-PAGE) using 2.5–20% acrylamide, at 25 V for 18 hours, according to Irwin *et al*,²⁹ with an interassay CV of < 9%.

Assay for LCAT activity

LCAT activity was assayed by conversion of ³H unesterified cholesterol to ³H esterified cholesterol, according to the method of Glomset *et al*,³⁰ modified by Knipping,³¹ as described previously,²¹ with an interassay CV of 4.5%. LCAT activity was expressed as nmol esterified cholesterol/h/ml of serum.

STATISTICAL ANALYSIS

The differences between macrosomic and appropriate for gestational age newborns, and between diabetic and healthy mothers were assessed by one way analysis of variance (ANOVA), followed by the inspection of all differences by Duncan's multiple range test. Differences were considered significant at $p < 0.05$. Simple and multiple linear regression were used to test for an association between study variables. Both Pearson's and non-parametric Spearman correlation coefficients were calculated for the assessment of the relations of fetal lipid and lipoprotein param-

eters with birth weight, fetal insulin, maternal glucose, maternal Hb A1, maternal lipids, and maternal lipoproteins. Multiple regression analysis was used to model the relations between maternal and fetal parameters. Variables were analysed further with logistic regression to determine the magnitude of their independent association with lipid and lipoprotein alterations related to fetal macrosomia. Fetal macrosomia (present or absent) and fetal lipoprotein parameters were the outcome variables in the logistic regression analysis. Predictor variables included maternal diabetes (present or absent), maternal Hb A1, and maternal and fetal lipid status. All statistical procedures were performed with a statistical software package (STAT VIEW J4.02; Abacus Concepts, Berkeley, California, USA).

Results

LIPOPROTEIN PROFILES IN MOTHERS

Table 2 presents serum lipid, apo A-I and apo B100 concentrations, and LCAT activity in diabetic and healthy mothers, and in their respective newborns. Serum TG and apo B100 values were significantly higher, whereas serum apo A-I was lower in mothers with poorly controlled diabetes (group 1) than in mothers with well controlled diabetes (group 2) and healthy mothers (groups 3 and 4). Apo A-I to apo B100 ratios were lower in group 1 than groups 2–4 (mean, 0.65 (SEM, 0.10) *v* mean, 1.35 (SEM, 0.08); $p < 0.05$). No significant differences in serum lipid and apolipoprotein values were detected between mothers with well controlled diabetes and non-diabetic healthy subjects. LCAT activity in mothers with diabetes was similar to that found in healthy mothers.

Table 3 shows the mass and composition of each lipoprotein fraction (VLDL, LDL, HDL₂, and HDL₃). In mothers with poorly controlled diabetes, VLDL concentrations were higher whereas HDL₃ values were lower when compared with other groups. In addition, these mothers with poorly controlled diabetes had significantly higher VLDL, HDL₂, and HDL₃ TG values and lower HDL₃ cholesterol values than those in other groups. No differences were noted between well controlled diabetic and non diabetic groups.

Table 3 Serum lipoprotein concentrations and composition of mothers and their newborns

	Mothers				Newborns			
	Group 1	Group 2	Group 3	Group 4	Group 1	Group 2	Group 3	Group 4
VLDL								
Mass	3.81 (0.20)*	2.62 (0.18)**	2.81 (0.16)**	2.47 (0.27)**	1.42 (0.10)*	0.57 (0.11)**	0.70 (0.06)**	0.65 (0.08)**
Triglycerides	2.43 (0.15)*	1.71 (0.05)**	1.75 (0.10)**	1.66 (0.04)**	0.60 (0.03)*	0.16 (0.05)**	0.27 (0.04)**	0.20 (0.03)**
Cholesterol	0.72 (0.05)	0.67 (0.05)	0.74 (0.04)	0.65 (0.06)	0.61 (0.04)*	0.20 (0.03)**	0.27 (0.03)**	0.24 (0.02)**
LDL								
Mass (g/l)	4.92 (0.31)	4.44 (0.43)	4.80 (0.22)	4.62 (0.31)	1.30 (0.10)*	0.70 (0.08)**	0.60 (0.11)**	0.65 (0.10)**
Triglycerides	0.91 (0.06)	0.82 (0.06)	0.75 (0.06)	0.70 (0.08)	0.31 (0.03)*	0.13 (0.02)**	0.16 (0.04)**	0.12 (0.02)**
Cholesterol	4.10 (0.22)	3.89 (0.28)	3.95 (0.15)	3.70 (0.26)	0.72 (0.04)*	0.30 (0.04)**	0.35 (0.03)**	0.33 (0.05)**
HDL₂								
Mass	3.01 (0.24)	2.85 (0.21)	2.83 (0.24)	2.76 (0.28)	1.92 (0.1)*	1.45 (0.1)**	1.55 (0.08)**	1.52 (0.07)**
Triglycerides	0.51 (0.04)*	0.22 (0.03)**	0.20 (0.03)**	0.15 (0.04)**	0.31 (0.03)*	0.14 (0.04)**	0.15 (0.03)**	0.14 (0.03)**
Cholesterol	1.30 (0.12)	1.26 (0.15)	1.33 (0.11)	1.28 (0.13)	0.52 (0.05)**	0.75 (0.03)*	0.81 (0.04)*	0.76 (0.03)*
HDL₃								
Mass	1.72 (0.10)**	2.61 (0.11)*	2.72 (0.08)*	2.56 (0.16)*	2.01 (0.20)	1.42 (0.11)	1.52 (0.13)	1.43 (0.08)
Triglycerides	0.44 (0.03)*	0.21 (0.04)**	0.23 (0.05)**	0.15 (0.04)**	0.32 (0.04)*	0.15 (0.02)**	0.16 (0.02)**	0.15 (0.03)**
Cholesterol	0.53 (0.04)**	0.76 (0.10)*	0.80 (0.08)*	0.82 (0.12)*	0.40 (0.05)*	0.42 (0.04)**	0.39 (0.03)**	0.43 (0.03)**

Mass is measured in g/litre; triglycerides and cholesterol are measured in mmol/litre.

Values are mean (SEM).

Group 1, mothers with poorly controlled diabetes and macrosomic newborns.

Group 2, mothers with well controlled diabetics and appropriate for gestational age newborns.

Group 3, healthy mothers with macrosomic newborns.

Group 4, healthy mothers with appropriate for gestational age newborns.

Lipoprotein mass was the sum of protein, triglyceride, phospholipid, unesterified cholesterol and cholesteryl ester contents of each fraction.

Values within a row with different numbers of asterisks are significantly different, $p < 0.05$.

Table 4 presents the apolipoprotein profiles of VLDL, HDL₂, and HDL₃. VLDL apo B100 and VLDL apo C-III were higher, whereas HDL₃ apo A-I and HDL₃ apo A-II values were lower in mothers with poorly controlled diabetes compared with the other groups. No significant differences were found in HDL₂ apolipoprotein concentrations between all groups.

LIPOPROTEIN PROFILES IN NEWBORNS

Macrosomic newborns of mothers with poorly controlled diabetes (group 1) had increased serum TG, phospholipid, unesterified cholesterol, cholesteryl ester, apo A-I, and apo B100 concentrations compared with the other newborn groups. However, the apo A-I to B100 ratio was lower in these newborns than in the other newborn groups (mean, 2.01 (SD, 0.30)

v mean, 3.50 (SD, 0.10); $p < 0.05$). In macrosomic newborns of healthy mothers (group 3), serum lipid and apolipoprotein values were similar to those obtained in appropriate for gestational age newborns (groups 2 and 4). LCAT activity tended to be greater in macrosomic than in appropriate for gestational age newborns, but the differences were not significant. In macrosomic newborns of mothers with poorly controlled diabetes, all lipoprotein values (VLDL, LDL, HDL₂, and HDL₃) were higher than in the other newborn groups. These newborns also had higher HDL₂ and HDL₃ TG values and lower HDL₂ cholesterol concentrations than the other newborn groups.

VLDL apo B100, HDL₂ apo A-I, HDL₂ apo A-II, HDL₃ apo A-I, and HDL₃ apo A-II values were higher in macrosomic newborns of moth-

Table 4 Serum VLDL, HDL₂ and HDL₃ apolipoprotein (apo) profiles (AU/L) in mothers and their newborns

	Mothers				Newborns			
	Group 1	Group 2	Group 3	Group 4	Group 1	Group 2	Group 3	Group 4
VLDL								
Apo B100	0.690 (0.013)*	0.313 (0.050)**	0.322 (0.045)**	0.244 (0.030)**	0.205 (0.023)*	0.071 (0.016)**	0.080 (0.017)**	0.068 (0.01)**
Apo C-II	0.063 (0.010)	0.052 (0.009)	0.063 (0.011)	0.084 (0.012)	0.043 (0.011)	0.032 (0.009)	0.036 (0.010)	0.04 (0.008)
Apo C-III	0.124 (0.021)*	0.050 (0.010)**	0.053 (0.008)**	0.060 (0.010)**	0.046 (0.012)	0.033 (0.009)	0.030 (0.008)	0.029 (0.009)
Apo E	0.059 (0.007)	0.061 (0.008)	0.060 (0.011)	0.081 (0.011)	0.030 (0.008)	0.025 (0.006)	0.031 (0.007)	0.027 (0.006)
HDL₂								
Apo A-I	0.683 (0.089)	0.723 (0.062)	0.761 (0.057)	0.770 (0.080)	0.480 (0.028)*	0.333 (0.040)**	0.361 (0.028)**	0.309 (0.026)**
Apo A-II	0.101 (0.021)	0.152 (0.030)	0.130 (0.040)	0.110 (0.040)	0.101 (0.013)*	0.053 (0.010)**	0.064 (0.008)**	0.058 (0.009)**
Apo C-II	0.036 (0.008)	0.044 (0.012)	0.032 (0.008)	0.043 (0.008)	0.042 (0.010)	0.028 (0.009)	0.030 (0.008)	0.034 (0.006)
Apo C-III	0.054 (0.009)	0.043 (0.008)	0.040 (0.009)	0.048 (0.010)	0.033 (0.007)	0.034 (0.005)	0.032 (0.004)	0.040 (0.007)
Apo E	0.032 (0.007)	0.041 (0.009)	0.035 (0.008)	0.032 (0.007)	0.031 (0.008)	0.050 (0.010)	0.041 (0.009)	0.053 (0.009)
HDL₃								
Apo A-I	0.323 (0.041)**	0.781 (0.051)**	0.863 (0.050)*	0.800 (0.053)*	0.462 (0.038)*	0.301 (0.042)**	0.345 (0.020)**	0.330 (0.027)**
Apo A-II	0.164 (0.024)**	0.290 (0.040)*	0.325 (0.033)*	0.282 (0.027)*	0.233 (0.044)*	0.135 (0.020)**	0.140 (0.021)**	0.152 (0.030)**
Apo C-II	0.073 (0.011)	0.057 (0.012)	0.074 (0.009)	0.063 (0.014)	0.049 (0.008)	0.044 (0.007)	0.050 (0.009)	0.032 (0.007)
Apo C-III	0.065 (0.010)	0.063 (0.012)	0.080 (0.008)	0.070 (0.011)	0.060 (0.010)	0.072 (0.011)	0.074 (0.012)	0.068 (0.010)
Apo E	0.056 (0.012)	0.060 (0.010)	0.055 (0.010)	0.051 (0.009)	0.037 (0.006)	0.042 (0.009)	0.043 (0.010)	0.039 (0.008)

Values are mean (SEM).

Group 1, mothers with poorly controlled diabetes and macrosomic newborns.

Group 2, mothers with well controlled diabetes and appropriate for gestational age newborns.

Group 3, healthy mothers with macrosomic newborns.

Group 4, healthy mothers with appropriate for gestational age newborns.

Values within a row with different numbers of asterisks are significantly different, $p < 0.05$.

AU/L, arbitrary units/litre of serum; on the densitometer tracing obtained after electrophoresis, the concentration of each apolipoprotein was calculated from the percentage of the area for each apolipoprotein relative to the total apolipoprotein concentration of each fraction. HDL, high density lipoprotein; VLDL, very low density lipoprotein.

ers with poorly controlled diabetes than in the other newborn groups.

RELATIONS BETWEEN MATERNAL AND FETAL PARAMETERS

There was no significant correlation between maternal and newborn lipid, apolipoprotein, and lipoprotein concentrations in non-diabetic groups (groups 3 and 4) and in mothers with well controlled diabetes (group 2). However, a highly significant positive correlation was found between maternal and macrosomic newborn TG values in the poorly controlled diabetic group ($r = 0.73$; $p < 0.001$). Maternal TG concentrations were also significantly correlated to macrosomic newborn apo B100 ($r = 0.60$; $p < 0.01$), and HDL₂ TG and HDL₃ TG values ($r = 0.56$ and $r = 0.58$, respectively; $p < 0.01$) in the poorly controlled diabetic group.

No significant correlation was noted between maternal or cord lipoprotein parameters and birth weight in all groups studied. Taking all groups together, there was no correlation between maternal Hb A1 or glucose concentrations and infant birth weight. However, in mothers with poorly controlled diabetes, Hb A1 and glucose concentrations in the third trimester were significantly correlated with birth weight ($r = 0.50$ and $r = 0.48$, respectively; $p < 0.05$). Indeed, in these mothers, Hb A1 and glucose concentrations also correlated significantly with macrosomic newborn TG and VLDL values (Hb A1: $r = 0.51$ and $r = 0.53$, respectively; $p < 0.05$; glucose: $r = 0.56$ and $r = 0.57$, respectively; $p < 0.01$).

Taking all groups together, no correlation was noted between cord lipid and lipoprotein parameters and insulin values. However, in macrosomic newborns of mothers with poorly controlled diabetes, serum TG ($r = 0.48$; $p < 0.05$), cholesterol ($r = 0.47$; $p < 0.05$), apo A-I ($r = 0.64$; $p < 0.01$), and apo B100 ($r = 0.5$; $p < 0.05$) values were significantly correlated with insulin concentrations.

Structured multiple regression analysis, which determines the independent contributions of maternal characteristics to the variations of fetal parameters, showed that the R^2 values (from 2% to 8%) are small, indicating that little of the variations in birth weight and fetal lipid metabolism are explained by maternal Hb A1 and lipoprotein measurements when all groups are combined. Maternal diabetes alone or fetal macrosomia alone were not significant predictors of fetal lipids and lipoproteins. However, fetal variables can be predicted from the interaction of maternal diabetes and fetal macrosomia. In this case, maternal Hb A1 and glucose were associated with birth weight and explained 28% and 25%, respectively, of the variation in birth weight. Maternal Hb A1 was associated with fetal TG and VLDL, and explained 27% and 30%, respectively, of the variation in fetal TG and VLDL. Maternal TG was associated with fetal TG and explained 46% of the variation in fetal TG.

Discussion

Our study was performed on mothers with type 1 diabetes and their newborns to detect lipoprotein abnormalities at birth, in relation to maternal disorders. Our data showed that under appropriate metabolic control, type 1 diabetes did not affect maternal and fetal lipid values. However, when poorly controlled, type 1 diabetes was associated with maternal and fetal lipoprotein abnormalities. In agreement with previous findings,^{32,33} there was no correlation between maternal Hb A1 and birth weight. In healthy pregnancies, a varying contribution might be made by the genetic background of the fetus. In addition, in macrosomic newborns of healthy mothers, serum lipid, apolipoprotein, and lipoprotein values did not differ significantly from those of appropriate for gestational age newborns, in agreement with the results of Rovamo *et al.*³⁴ On the other hand, the infants born to mothers with poorly controlled diabetes might have been exposed to a hyperglycaemic milieu in utero, which resulted in macrosomia.

Mothers with poorly controlled diabetes showed high serum TG, apo B100, and VLDL values and low serum apo A-I and HDL₃ concentrations when compared with healthy mothers. These results differ from those of Kilby *et al.*,³³ who found no significant differences between serum lipids and apolipoproteins in pregnant women with type 1 diabetes and normal pregnant women, despite high Hb A1 values in patients with type 1 diabetes. Montelongo and colleagues¹⁰ hypothesised that the development of excess hyperlipidaemia in diabetic pregnancy depends on the balance between the degree of glycaemic control and the plasma sex hormone values during pregnancy. Indeed, in our study, all the infants of these mothers with poorly controlled diabetes were macrosomic at birth, which is an indicator of maternal hyperglycaemia in late pregnancy, and is contrary to the results of previous studies.^{9,10,33}

Our results showed that mothers with poorly controlled diabetes had increased serum TG, apo B100, and VLDL values, probably as a result of both overproduction induced by pregnancy⁸ and decreased catabolism related to a failure of lipoprotein lipase (LPL) activity secondary to insulin deficiency. In addition, VLDL apo C-III, an inhibitor of LPL action, was increased in the mothers with type 1 diabetes. These mothers also showed several modifications in HDL₂ and HDL₃ composition and concentration; however, LCAT activity, which is responsible for cholesterol esterification and which modulates HDL composition, was similar to that found in healthy mothers. Although HDL₃ TG values were increased, HDL₃ apo A-I and HDL₃ apo A-II values were decreased in mothers with type 1 diabetes. These data suggest a reduction in HDL₃ particle number, with changes in their composition that could affect reverse cholesterol transport. Decreased nascent HDL synthesis or reduced VLDL catabolism could be factors that contribute to low HDL₃ values in the mothers with poorly controlled diabetes. In addition, HDL₂

and HDL₃ particles were TG enriched owing to impaired removal of VLDL TGs or decreased hepatic lipase (HL) activity.

In macrosomic newborns of mothers with poorly controlled diabetes, serum lipid and apolipoprotein values were higher than in control newborns. These data show that fat and protein synthesis was increased in those fetuses with overnutrition, and are in agreement with earlier reports.³⁵⁻³⁷ In children and adults, obesity is associated with increased concentrations of plasma lipids.³⁸⁻³⁹ Kilby *et al* also showed increased serum lipids and apolipoproteins in infants of mothers with type 1 diabetes, despite their normal birth weight.³⁵ Indeed, in that study, mothers with type 1 diabetes had only minor lipoprotein changes, although their Hb A1 values were significantly higher than controls.³³ In our study, macrosomic newborns showed higher serum VLDL values accompanied by an increase in serum TG and apo B100 values. An enhancement in glucose and free fatty acid transfer from the mother could explain raised hepatic VLDL secretion and hypertriglyceridaemia, because glucose and free fatty acids are major substrate determinants for hepatic VLDL secretion.⁴⁰ Indeed, hyperinsulinaemia boosted lipid and protein synthesis. In our study, highly significant positive correlations between (1) maternal Hb A1, glucose, and TG values and neonate TG and VLDL concentrations, and (2) between cord serum insulin values and lipid and apolipoprotein concentrations support these findings. Macrosomic newborns also showed high LDL values, as a result of high concentrations of VLDL, because most LDL particles are derived from VLDL after the action of LPL. Macrosomic newborns had higher HDL₂ and HDL₃ values, which were accompanied by higher HDL apo A-I and HDL apo A-II concentrations, suggesting an increase in the number of HDL particles, probably as a result of their enhanced synthesis. In these newborns, LCAT activity was not significantly different from that found in control newborns, despite high concentrations of apo A-I (its major cofactor). HDL₂ and HDL₃ particles were enriched in TGs, whereas amounts of HDL₂ cholesteryl ester were low. A possible increase in the interchange of lipids between lipoproteins resulting from high cholesteryl ester transfer protein (CETP) activity could contribute to the increase in HDL₂ and HDL₃ TGs and the decrease in HDL₂ cholesteryl ester values. Neary *et al* showed a reduction in cholesteryl ester transfer activity in the mother during normal pregnancy, with an even greater reduction in the fetus.⁴¹ However, plasma CETP values could be enhanced in macrosomic newborns, as is found in obese adults, because adipose tissue is a major source of CETP.⁴² Further analysis of CETP activity in these macrosomic newborns is needed.

Lipoprotein profiles in macrosomic newborns of mothers with poorly controlled diabetes are consistent with high atherogenic risk. Thus, persisting lipoprotein abnormalities in macrosomic infants could be one of the

processes that link macrosomia to adult metabolic diseases.²⁵

In conclusion, under appropriate metabolic control, type 1 diabetes did not affect maternal and fetal lipid values. In addition, macrosomia in non-diabetic pregnancy was not associated with lipoprotein changes. However, lipoprotein metabolism was altered in mothers with type 1 diabetes and poor glycaemic control, and in their macrosomic newborns. Hypertriglyceridaemia with high VLDL concentrations, TG enrichment in HDL particles, and a low apo A-I to apo B100 ratio were major changes in mothers with type 1 diabetes and in their macrosomic newborns. Persistent macrosomic lipoprotein alterations might be an important risk factor for later metabolic diseases. Macrosomia should be prevented in type 1 diabetic pregnancy to reduce the risk of the later development of metabolic diseases. In addition, special health care for these macrosomic infants should be recommended, including regular examinations and dietary advice.

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