Composition of the human foetus

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1. The body composition was determined of forty-one foetuses of different gestational ages born to mothers belonging to a low socio-economic group of the population.

2. With increasing gestational age the water content fell from 88 % at 28 weeks to 76 % at term; the fat content increased from 2·1 % to 11·2 % and the protein content increased from 6·9 to 9·3 %.

3. The changes in body composition were more closely related to body-weight than to gestational age.

4. The calcium, phosphorus and magnesium contents of the body per unit fat-free weight progressively increased with gestational age, and at term the values appeared to be considerably lower than those reported in the literature. The Ca:P ratio was constant at different body-weights.

5. The body iron content per unit of fat-free weight increased marginally with increasing gestational age. This value was almost 30 % lower than the values reported from elsewhere.

6. It is suggested that chemical composition and nutrient stores of the developing foetus can be considerably influenced by the state of maternal nutrition.

Satisfactory growth and development of the foetus may be expected to depend to a great extent on the diet and nutritional status of the mother. The chemical composition of the human foetus at different stages of gestation will provide base-line information not only on the chemistry of growth and development but also on the effects of maternal malnutrition on the body composition of the growing foetus.

While there is a good deal of information about the anthropometric measurements of the human foetus at varying gestational periods, information on the body composition at different stages of intra-uterine growth is limited. It is perhaps surprising that reported information on such a vital aspect of chemical development *in utero* is restricted to about only 120 foetuses; of these, about fifty were analysed around AD 1900. Since information regarding the source of this material was not clearly indicated, Kelly, Sloan, Hoffman & Saunders (1951), in their review, have questioned the validity of these findings. More recent results are available for about seventy foetuses, which have been analysed for various body constituents (Givens & Macy, 1933; Iob & Swanson, 1934; Widdowson & Dickerson, 1964). Information on the total body iron content of twenty-five foetuses has been reported by Widdowson & Dickerson (1964).

All these reports are from Europe and America and it may be presumed that the foetuses were born to well-nourished mothers. There are virtually no values for the body composition of foetuses born to mothers of the low socio-economic group whose dietary intake during pregnancy is far from satisfactory and among whom signs of malnutrition are frequently observed. The results of an investigation in which the body composition and mineral stores were determined in forty-one human foetuses of such malnourished mothers are presented here.

MATERIALS AND METHODS

Twenty-three immature foetuses of varying gestational ages and eighteen full-term infants born to mothers attending the Niloufer Hospital, Hyderabad, were obtained. The mothers belonged to the poor groups of the population, the family income generally being less than Rs. 150 per month. These women were similar to those studied earlier by Venkatachalam (1962), who had reported that they were undernourished, having a mean body-weight of about 42 kg. They had clinical evidence of varying degrees of calorie and protein deficiency, vitamin B-complex deficiency and hypovitaminosis A. A mild to moderate anaemia was widely prevalent. The mean daily intakes of calories and protein were estimated to be 1400 kcal and 40 g respectively. The intake of other nutrients was found to be grossly inadequate. Most of the women had not received any antenatal care. The gestational age was arrived at from information about the last menstrual period and may therefore be considered as approximate, the variation, however, being not greater than ± 7 d. Body-weights of the infant have therefore been used as a reference standard for expressing body composition.

Twenty-nine foetuses were stillborn and twelve were born alive but expired within 24 h. In sixteen the cause of stillbirth was either prepartum haemorrhage, eclampsia or compound presentation; in the other thirteen no cause could be detected.

Preparation and analytical methods

All the foetuses were preserved at 4° before autopsy, which was usually performed within 6–8 h of death. They were dissected to small pieces in an aluminium tray to prevent loss of blood. The liver was removed, washed and analysed separately (Iyengar & Apte, 1972). The dissected foetuses were dried in a hot-air oven at 90–100° for 15–20 d. The whole dried foetus was powdered in small quantities at a time in a glass mortar and pestle. All the powdered lots were thoroughly mixed and stored dry at room temperature. Duplicate samples of 5–10 g of the whole carcass powder were initially used for determination of fat. Samples of fat-free powder were used for determination of nitrogen, calcium, phosphorus, magnesium and iron.

Fat was determined by ether extraction in Soxhlet's apparatus for 16 h. N was determined by the micro-Kjeldhal method with aeration into boric acid and tritation (Oser, 1965). N conversion into protein was calculated by the factor 6·25. Ca was measured by the method of Clark & Collip (1925), P by the method described by the Association of Official Agricultural Chemists (1960), Mg by the method of Orange & Rhein (1951) and Fe by a thiocyanate method (Wong, 1928).

RESULTS

The results are presented in Tables 1–3 and are compared with those reported by Widdowson (1968) in Table 4.

Water, protein and fat

Foetal body-weight, fat and protein concentration increased, and water concentration decreased with increasing time of gestation. The concentrations of water, fat and protein (Y) in the developing foetus were significantly correlated with body-weight (x), the regression equations being

$$\text{Water: } Y = 91.92 - 0.0059x \quad (r = -0.8581)^{***};$$
$$\text{Fat: } Y = 0.0049x - 2.25 \quad (r = +0.3338)^{*};$$
$$\text{Protein: } Y = 7.33 + 0.00078x \quad (r = +0.3338).^{*}$$
$$^{*}\ P < 0.05; \quad ^{***}\ P < 0.001.$$

There was a progressive fall in the concentration of water with increasing body-weight. The water content (g/100 g wet weight) of the smallest foetus, weighing 0·23 kg, was about 93%, whereas that of the foetus weighing 3·3 kg was about 72%. Body water expressed as a percentage of lean body mass fell from 91% to about 84% when the weight was about 3·3 kg. Fat constituted 0·3 g/100 g body-weight at 0·23 kg and 16 g/100 g at 3·3 kg body-weight. The protein concentration increased from a mean of 6·9 g/100 g at gestational age below 28 weeks to 9·3 g/100 g at term. There appeared to be no significant difference in this respect between foetuses of different body-weights at term. Similarly, the percentage of fat increased progressively from some 2·1 g/100 g below 28 weeks to 5·6 g/100 g at term in foetuses whose body-weights were below 2·25 kg and to 11·2 g/100 g in foetuses whose body-weights were above 2·25 kg.

Ca, P and Mg

A steady increase in the absolute amounts of Ca, P and Mg was observed with increasing body-weight, the total amounts at 3·3 kg body-weight being fourteen and fifteen times that of the foetus weighing 0·34 kg (Table 3). On a fat-free basis the percentage also increased, the concentration of Ca at term being little less than twice, and that of P being about 1·7 times, that found in a foetus weighing 0·34 kg. The Mg concentration steadily increased up to a body-weight of 1·70 kg and thereafter remained stationary. The Ca:P ratio remained relatively constant within a range of 1·6–2·1 at different body-weights.

Fe

The total amount of Fe in the foetuses at different body-weights is shown in Fig. 1. The increase in the absolute amount of Fe showed a linear relation with body-weight. The concentration of Fe per 100 g fat-free body-weight, however, increased only slightly, from 5·3 mg at 0·23 kg body-weight to 6·4 mg at 3·3 kg. There were wide variations among the values at any one body-weight.

Table 1. *Body composition of the human foetus*

Age (weeks)	Body-wt (g)	Water (%)	Fat (%)	Protein (%)	Ash (%)	Ca (%)	P (%)	Mg (mg/100 g)	Fe (mg/100 g)
20	230	93·2	0·3	4·0	1·15	0·322	0·241	12·0	4·5
24	450	88·2	1·1	8·3	1·95	0·557	0·294	19·2	5·9
24	790	89·0	1·5	6·7	1·96	0·704	0·340	17·0	5·1
26	655	90·6	1·5	6·4	1·45	0·502	0·269	14·3	3·6
26	570	83·9	2·0	9·2	2·53	0·834	0·514	27·3	5·0
26	810	90·8	0·7	7·0	1·40	0·387	0·271	17·1	4·1
26	1035	87·0	1·4	7·9	2·19	0·686	0·355	22·3	4·3
26	1320	81·8	8·1	6·1	2·24	0·613	0·325	17·2	5·2
28	1030	82·5	2·0	11·7	2·73	0·700	0·575	23·5	5·8
28	1100	80·5	5·0	11·9	2·53	0·392	0·337	20·0	6·9
29	1210	89·7	2·3	5·9	1·45	0·429	0·241	13·3	3·8
29	1560	85·1	3·4	7·7	2·32	0·835	0·424	13·6	4·2
30	1420	89·0	1·4	7·9	2·42	0·720	0·457	19·6	5·6
30	1425	81·1	4·3	9·7	2·72	0·924	0·529	20·6	5·8
32	925	89·2	1·6	5·9	2·19	0·303	0·418	17·5	4·2
32	1100	84·8	3·6	7·4	2·23	0·688	0·358	11·8	6·9
32	1150	82·6	2·7	10·3	3·19	1·151	0·637	23·1	7·2
32	1340	83·9	5·5	7·1	2·18	0·769	0·413	12·4	5·4
35	1055	87·0	2·6	7·4	1·74	0·623	0·276	16·9	5·2
35	1840	81·9	5·7	8·8	2·55	0·389	0·222	21·1	4·1
36	1290	83·0	4·4	10·1	2·40	0·898	0·417	21·6	5·9
36	1520	84·1	4·2	9·0	1·89	0·757	0·364	19·4	6·1
36	1570	81·0	5·9	7·8	2·19	0·849	0·395	24·1	5·7
37	1800	83·3	4·4	9·3	2·54	0·928	0·504	24·7	6·1
38	2230	78·3	8·1	8·6	2·05	0·656	0·512	21·7	4·5
38	2495	74·7	13·0	7·3	1·73	0·781	0·313	20·5	7·1
38	2600	75·2	12·4	8·9	1·95	0·718	0·374	18·9	4·1
38	2645	78·1	8·6	10·0	2·09	0·727	0·374	21·9	5·8
40	1090	83·8	2·8	10·7	2·49	0·762	0·456	22·4	5·5
40	1975	82·0	5·5	8·5	1·45	0·527	0·297	18·6	6·1
40	2000	79·3	7·4	11·1	2·01	0·625	0·354	16·1	4·3
40	2010	78·3	5·6	11·2	2·41	0·879	0·604	28·3	5·3
40	2270	76·5	9·3	10·0	2·54	0·849	0·471	18·6	6·2
40	2280	74·7	11·7	10·9	1·64	0·391	0·247	16·9	6·4
40	2400	80·6	9·0	6·3	2·33	0·844	0·432	19·5	5·4
40	2505	73·2	12·6	10·4	3·17	1·050	0·522	21·7	6·4
40	2535	74·0	12·4	9·3	2·37	0·879	0·352	21·5	4·3
40	2600	78·7	6·7	10·5	3·41	1·064	0·526	29·8	7·1
40	2680	78·5	11·6	9·3	1·11	0·304	0·179	15·1	3·3
40	3270	78·3	11·3	7·8	1·65	0·558	0·312	16·1	5·5
40	3340	71·5	15·8	9·2	2·61	0·934	0·469	27·8	5·6

Table 2. *Body composition of the human foetus*

(Mean values with their standard errors; figures in parentheses are the numbers of foetuses studied)

Age (weeks)	Body-weight (g)	Water (g/100 g)	Fat (g/100 g)	Protein (g/100 g)	Ash (g/100 g)
< 28 (8)	733·4 ± 120·04	88·1 ± 1·33	2·1 ± 0·88	6·9 ± 0·56	1·9 ± 0·17
28–32 (10)	1225·7 ± 64·07	84·8 ± 1·08	3·2 ± 0·45	8·6 ± 0·70	2·4 ± 0·15
33–36 (5)	1454·4 ± 132·55	83·8 ± 1·05	4·6 ± 0·59	8·6 ± 0·48	2·2 ± 0·15
37–40:					
Body-wt < 2250 g (6)	1850·0 ± 162·02	80·8 ± 1·03	5·6 ± 0·79	9·9 ± 0·51	2·2 ± 0·17
Body-wt > 2250 g (12)	2635·3 ± 97·90	76·2 ± 0·78	11·2 ± 0·70	9·3 ± 0·36	2·2 ± 0·19

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Table 3. *Calcium, phosphorus and magnesium content of the human foetus*

(Mean values with their standard errors; figures in parentheses are the numbers of foetuses studied)

Body-wt range (g)	Ca content g	Ca content g/kg fat-free tissue	P content g	P content g/kg fat-free tissue	Ratio Ca:P	Mg content g	Mg content g/kg fat-free tissue
200–500 (2)	1·63 ± 0·882	4·43 ± 1·200	0·92 ± 0·400	2·72 ± 0·255	1·60 ± 0·291	0·062 ± 0·0340	0·158 ± 0·0370
500–800 (3)	4·54 ± 0·662	6·91 ± 1·098	2·46 ± 0·362	3·81 ± 0·749	1·85 ± 0·130	0·128 ± 0·0058	0·199 ± 0·0390
800–1100 (6)	7·08 ± 0·784	7·19 ± 1·070	3·93 ± 0·550	4·01 ± 0·492	1·81 ± 0·110	0·198 ± 0·0059	0·204 ± 0·0043
1100–1400 (7)	8·61 ± 1·242	7·39 ± 1·030	4·73 ± 0·557	4·08 ± 0·478	1·78 ± 0·115	0·216 ± 0·0759	0·180 ± 0·0563
1400–1700 (5)	12·25 ± 0·604	8·51 ± 0·041	6·40 ± 0·271	4·46 ± 0·247	1·92 ± 0·105	0·291 ± 0·0836	0·203 ± 0·0483
1700–2000 (3)	11·41 ± 2·800	6·47 ± 1·672	6·34 ± 1·454	3·59 ± 0·869	1·79 ± 0·021	0·377 ± 0·0368	0·225 ± 0·0059
2000–2300 (5)	14·59 ± 1·842	7·43 ± 1·090	9·39 ± 1·278	4·76 ± 0·642	1·59 ± 0·094	0·436 ± 0·0423	0·221 ± 0·0738
2300–2600 (4)	22·07 ± 1·534	10·07 ± 1·068	10·62 ± 1·096	4·82 ± 0·506	2·13 ± 0·146	0·530 ± 0·0085	0·261 ± 0·0009
2600–2900 (4)	18·42 ± 3·995	7·76 ± 1·672	9·53 ± 1·818	3·99 ± 0·762	1·86 ± 0·076	0·562 ± 0·0797	0·234 ± 0·0321
3200–3500 (2)	24·73 ± 0·465	8·68 ± 2·410	12·92 ± 2·706	4·53 ± 1·025	1·89 ± 0·100	0·728 ± 0·6311	0·256 ± 0·0736

Table 4. *Total amounts of water, fat, protein and some minerals in the developing human foetus at body-weights of* 1000, 1500, 2000, 2500 *and* 3000 *g*

	1000 g		1500 g		2000 g		2500 g		3000 g	
	Present work	Widdowson (1968)	Present work	Widdowson (1968)	Present work	Widdowson (1968)	Present work	Widdowson (1968)	Present work	Widdowson (1968)
Age (weeks)	27	26	34	31	38	33	40	35	40	38
Water (g)	862	860	1248	1270	1604	1620	1935	1940	2238	2180
Protein (g)	80	87·5	126	156	176	231	242	306	291	344
Fat (g)	26	10	75	35	148	100	242	185	366	360
Calcium (g)	5·8	6·0	10·5	10·0	14·6	15·0	19·0	20	22·7	25·0
Phosphorus (g)	3·3	3·4	5·0	5·6	8·6	8·2	10·8	11·0	11·4	14·0
Magnesium (mg)	200	220	325	350	425	460	540	580	655	700
Iron (mg)	59	64	81	100	108	160	138	220	165	260

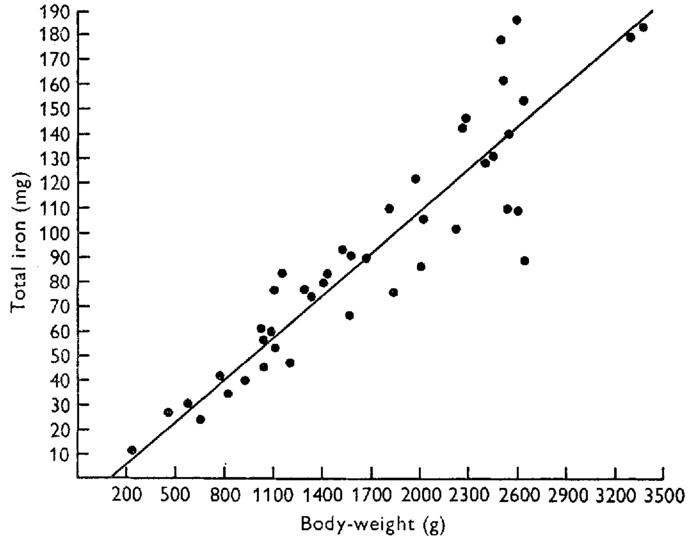

Fig. 1. Total iron in the human foetus. Regression equation relating total iron (Y) to body-weight (x): $Y = 0{\cdot}0560x - 3{\cdot}70$ ($r = +0{\cdot}9145$)***.
*** $P < 0{\cdot}001$.

DISCUSSION

With increasing body-weight one of the striking changes in the body composition was the decrease in water content, both in relation to total body-weight and in relation to fat-free body-weight. A similar but more marked decrease in water content has been reported by Widdowson & Spray (1951) in foetuses in the United Kingdom. The fat content of foetuses studied here was similar to that of those studied by Widdowson & Spray (1951) at all weights. In fact, in foetuses of 40 weeks gestation weighing 2·50 kg, the fat content was slightly higher than that reported by Widdowson & Spray (1951) for foetuses of similar weight, but of only 35 weeks gestation. It is possible that this difference is an expression of foetal maturity. The results of the present investigation indicate that the amount of fat deposited in the developing foetus is more closely related to body-weight than to period of gestation. The low fat content of foetuses studied here may be a reflection of the low body-weight. The percentage of fat in foetuses at term studied here is similar to that reported by Shohl (1939).

The N content of foetuses at all body-weights was distinctly lower than that observed by Widdowson & Spray (1951). At about 20 weeks of gestational age, foetuses analysed here contained 0·7 g/100 g as compared with 1·3 g/100 g reported by Widdowson & Spray (1951). However, during the last 20 weeks of development an increment of 1 g/100 g in N content was observed in both studies. The results could be interpreted as indicating that, in the initial phases of development, foetuses in the present study had more water and less protein, but similar amounts of fat compared with those studied by Widdowson & Spray (1951). Examination of our results and those of Widdowson & Spray (1951) indicates that, in both series, with the development of the foetus the protein and fat content increased almost similarly. However, it would appear that the water content decreased at different rates in the two series.

Total Ca and P contents of the foetuses were similar to reported values up to a body-weight of 2 kg. However, foetuses of body-weight greater than 2 kg tended to have slightly smaller amounts of Ca and P than those of Widdowson (1968). The total Mg content of Indian foetuses was lower by 6–9% than that of Western foetuses at each body-weight.

There were wide variations in the total Fe content of foetuses of the same weight, an observation similar to that reported in the literature (Widdowson & Spray, 1951). The total Fe content of foetuses in the present study, however, was significantly lower than that of Western foetuses at all weights. This was also true of the concentration of Fe/100 g fat-free weight.

On the basis of body-weight, at 26–28 weeks of gestational age the foetuses in this series were similar to those from the West, but beyond this period there appeared to be a definite lag in body-weight of roughly 3–5 weeks. It may, however, be considered significant that, even when the body-weights were similar, their composition was slightly different, there being a marked deficit in the protein and Fe contents. The total protein content was lower by 8% in the earlier stages and by as much as 23% in the later stages of development. Similarly the Fe content was lower by 20% at all stages. In our series the fat contents of foetuses weighing 1 and 1·5 kg were 26 g and 75 g respectively. The lower fat content (10 g and 35 g) of British foetuses of similar body-weight (Table 4) is intriguing, since Widdowson (1968) in the same paper had observed that the percentage of fat at a body-weight of 1·2 kg and foetal age of 28 weeks was about 3·5%.

It is difficult to explain the low amounts of protein in the foetuses of the present study. It may be a reflection of the poor nutritional status of the mother. The low Ca and Fe contents may again perhaps be due to inadequate intake of these nutrients by the pregnant mothers.

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REFERENCES

Association of Official Agricultural Chemists (1960). *Official Methods of Analysis* 9th ed., p. 84. Washington, DC: Association of Official Agricultural Chemists.

Clark, E. P. & Collip, J. B. (1925). *J. biol. Chem.* **63**, 461.

Givens, M. H. & Macy, I. G. (1933). *J. biol. Chem.* **102**, 7.

Iob, V. & Swanson, W. W. (1934). *Am. J. Dis. Child.* **47**, 302.

Iyengar, J. & Apte, S. V. (1972). *Br. J. Nutr.* **27**, 313.

Kelly, H. J., Sloan, R. E., Hoffman, W. & Saunders, C. (1951). *Hum. Biol.* **23**, 61.

Orange, M. & Rhein, H. C. (1951). *J. biol. Chem.* **189**, 379.

Oser, B. L. (1965). *Hawk's Physiological Chemistry* 14th ed., p. 1219. New York: McGraw-Hill Book Company.

Shohl, A. T. (1939). *Mineral Metabolism.* American Chemical Society Monograph Series. New York: Reinhold Publishing Corporation.

Venkatachalam, P. S. (1962). *Bull. Wld Hlth Org.* **26**, 193.
Widdowson, E. M. (1968). In *Biology of Gestation* Vol. 2, p. 23 [N. S. Asali, editor]. New York: Academic Press.
Widdowson, E. M. & Dickerson, J. W. T. (1964). In *Mineral Metabolism* Vol. 2, Part A *The Elements, Processes and Systems* p. 26 [C. L. Comer and F. Bronner, editors]. New York: Academic Press.
Widdowson, E. M. & Spray, C. M. (1951). *Archs Dis. Childh.* **26**, 205.
Wong, S. Y. (1928). *J. biol. Chem.* **77**, 409.

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