THE CHEMICAL COMPOSITION OF THE HUMAN FETUS*

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In order to provide sufficient nourishment for both mother and fetus it is important to know how much material is laid down in the fetus at different periods of its development. This is consequential, not only for the sake of determining the requirements for fetal nutrition itself, but for appraising the nutritive drain on the maternal body at various stages of gestation. Slemons (2) says there are two ways of estimating the substances required for fetal nutrition; first, by assuming that the requirements of the fetus are similar to those of the new-born which is maintained by its mother's milk and secondly, by analyzing the body of the fetus on the supposition that the substances found therein represent its requirements for growth.

This report deals with the length, wet weight, dry weight or total solids, water, total ash, calcium, and magnesium content of twenty-five human fetuses ranging from 2 to 8 months in age. In addition, these data are summarized together with the available analyses in the literature (3–9) thus giving in toto the chemical composition of 96 human fetuses ranging from 1½ to 10 lunar months in age from which growth diagrams have been constructed.

* The chemical analyses were made by the writers in the Research Laboratories of the Western Pennsylvania Hospital, Pittsburgh, and a preliminary report was given before the Sixteenth meeting of the American Society of Biological Chemists at New Haven, December 28–30, 1921 (1).

We are indebted to Dr. J. Morris Slemons, at the time Professor of Obstetrics, Yale Medical School, for some of the fetuses; also we acknowledge and appreciate the courtesy of the staff of the Western Pennsylvania Hospital, in particular Dr. V. L. Andrews, for other specimens.
Chemical Composition of Human Fetus

EXPERIMENTAL

The fetuses used in this study were collected at the time of adverse conditions in pregnancy or labor. All specimens were preserved in either alcohol or formaldehyde with but two exceptions and they were kept on ice until the analyses were begun. The cord and all extraneous materials were removed before the body weights were taken. After the crown-heel length was measured with a metal tape each fetus was placed in a weighed porcelain crucible and brought to a constant weight in a low temperature oven. Incineration was begun over the open flame and when carbonization had taken place the ashing was completed in the muffle furnace. The modified McCrudden method (10) was used in the determination of calcium and magnesium in the ash.

DISCUSSION

It is not possible to determine fetal age with any certainty because in any particular case too little is known of the exact time relations existing between menstruation and ovulation, and between ovulation, coitus, and fertilization (11). The age of the fetus dates from the moment of fertilization to the cessation of development. In specimens obtained by operation or abortion this period may be known; in others it is not. The indefiniteness attached to the estimate of the age of the fetus necessarily vitiates the accuracy of any growth diagram that may be constructed and, consequently, any computation of the weight or length of the human fetus at various periods in intrauterine life is very inexact. The results from the analyses of embryos of various ages, however, are of distinct value since they do give a close approximation of fetal requirements.

In the twenty-five new cases reported in Table I, the ages of the fetuses have been calculated by applying the simple, modern, age-size formula of Arey (12). By this formula the age in lunar months is determined by multiplying the crown-heel length in cm. by 0.2. No corrections were made for the three fetuses falling below 10 cm. because their length fell within so close a proximity. Human fetuses of the same length may vary widely in chemical composition.

Although there are marked variations between fetuses of the same length, there is a definite relationship between age and
average composition as illustrated graphically in the semilogarithmic Chart 1 which summarizes the chemical analyses of 96 human fetuses. The age in lunar months is plotted on the horizontal arithmetic scale and the weights and lengths of the fetuses on the

**TABLE I**

**Composition of Human Fetus**

<table>
<thead>
<tr>
<th>Fetus No.</th>
<th>Sex</th>
<th>Crown-heel length</th>
<th>Age*</th>
<th>Weight</th>
<th>Ash</th>
<th>Calcium</th>
<th>Magnesium</th>
</tr>
</thead>
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<tr>
<td></td>
<td></td>
<td>cm.</td>
<td>lunar</td>
<td>gm.</td>
<td>gm.</td>
<td>gm.</td>
<td>per cent</td>
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<td>13</td>
<td>♂</td>
<td>9.0</td>
<td>1.8</td>
<td>6.4</td>
<td>0.49</td>
<td>0.02</td>
<td>4.1</td>
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<tr>
<td>8</td>
<td>♂</td>
<td>9.5</td>
<td>1.9</td>
<td>14.0</td>
<td>1.47</td>
<td>0.15</td>
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<td>1</td>
<td>♂</td>
<td>9.6</td>
<td>1.9</td>
<td>11.0</td>
<td>1.26</td>
<td>0.11</td>
<td>8.7</td>
</tr>
<tr>
<td>2</td>
<td>♂</td>
<td>10.6</td>
<td>2.1</td>
<td>19.0</td>
<td>2.27</td>
<td>0.20</td>
<td>8.3</td>
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<tr>
<td>10</td>
<td>♂</td>
<td>11.0</td>
<td>2.2</td>
<td>33.0</td>
<td>3.04</td>
<td>0.32</td>
<td>10.5</td>
</tr>
<tr>
<td>9</td>
<td>♂</td>
<td>11.5</td>
<td>2.3</td>
<td>32.0</td>
<td>4.40</td>
<td>0.60</td>
<td>13.6</td>
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<td>12.5</td>
<td>2.5</td>
<td>33.0</td>
<td>3.31</td>
<td>0.48</td>
<td>14.5</td>
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<td>3</td>
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<td>13.1</td>
<td>2.6</td>
<td>131.0</td>
<td>15.28</td>
<td>1.60</td>
<td>10.5</td>
</tr>
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<td>15</td>
<td>♂</td>
<td>15.0</td>
<td>3.0</td>
<td>71.0</td>
<td>7.16</td>
<td>1.02</td>
<td>14.2</td>
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<td>11</td>
<td>♂</td>
<td>16.0</td>
<td>3.2</td>
<td>86.0</td>
<td>8.90</td>
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<td>5</td>
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<td>3.7</td>
<td>128.0</td>
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<tr>
<td>17</td>
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<td>20.0</td>
<td>4.0</td>
<td>201.0</td>
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<td>1.87</td>
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<tr>
<td>12</td>
<td>♀</td>
<td>21.0</td>
<td>4.2</td>
<td>113.0</td>
<td>18.12</td>
<td>2.83</td>
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<tr>
<td>23</td>
<td>♀</td>
<td>21.0</td>
<td>4.2</td>
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<td>2.66</td>
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<td>16</td>
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<td>21.0</td>
<td>4.2</td>
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<td>24</td>
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<td>22.0</td>
<td>4.4</td>
<td>172.0</td>
<td>26.74</td>
<td>3.54</td>
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<tr>
<td>25</td>
<td>♀</td>
<td>23.5</td>
<td>4.7</td>
<td>360.0</td>
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<td>♀</td>
<td>24.0</td>
<td>4.8</td>
<td>312.0</td>
<td>37.73</td>
<td>4.92</td>
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<td>6</td>
<td>♀</td>
<td>24.1</td>
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<td>296.0</td>
<td>36.38</td>
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<td>7</td>
<td>♀</td>
<td>28.0</td>
<td>5.6</td>
<td>433.0</td>
<td>54.38</td>
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<td>15.8</td>
</tr>
<tr>
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<td>29.5</td>
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<td>314.0</td>
<td>65.89</td>
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<tr>
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<td>36.5</td>
<td>7.3</td>
<td>1107.0</td>
<td>177.62</td>
<td>35.85</td>
<td>20.2</td>
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<td>38.5</td>
<td>7.3</td>
<td>1071.0</td>
<td>161.37</td>
<td>18.69</td>
<td>11.6</td>
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<td>39.5</td>
<td>7.9</td>
<td>1060.0</td>
<td>199.00</td>
<td>17.59</td>
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<td>19†</td>
<td>♀</td>
<td>40.0</td>
<td>8.0</td>
<td>1170.0</td>
<td>266.5</td>
<td>42.64</td>
<td>16.0</td>
</tr>
</tbody>
</table>

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* Arey's formula = standing height (cm.) × 0.2 = age (months).
† Twins.
‡ Born September 30, 1920, at 12.08 a.m.; died 3.15 a.m.
§ Born September 30, 1920; died October 4, 1920.
Chart 1. Graph illustrating the relation of age to average chemical composition of the human fetus. The age is plotted in lunar months on the horizontal arithmetic scale and the average length, wet weight, total solids, water content, total ash, calcium, and magnesium on the vertical logarithmic scale. The total number of fetuses from which the averages figures of composition have been obtained for each particular age group is given within circles. This semilogarithmic graph not only shows the absolute value but also the relative rates of change in composition as age in utero progresses.
vertical logarithmic scale, thus showing not only the absolute values but the relative rate of change of values throughout intrauterine life. The number of cases from which the average figures of composition for each particular age group have been obtained is given in circles. In some instances, as in the case of magnesium, in which there are few cases in a particular age group, the irregularities in the curves may be partially explained by the small number of determinations. The length of the embryo increases very rapidly during the first 4 or 5 months, but the rate decreases during the remaining months. The percentage composition of water in the fetus gradually decreases from 92 at the 3rd month to 72 at maturity. From the number of cases presented it is evident that the fetal demand for total solids, total ash, and calcium increases progressively and at approximately the same rate with age during intrauterine life; whereas, magnesium storage increases at a much slower rate.

Growth of the fetus consists primarily in the transformation of inorganic salts, fats, carbohydrates, amino acids, etc., from the maternal blood into new chemical entities which form the fetal tissue. The fetus in utero depends on the maternal body not only for its immediate source of supply, but for a means of elimination of waste products of its metabolism. From a study of the calcium and mineral content of the tibiae secured post mortem in a series of newborn infants born to mothers of known nutritional histories, Booher and Hansmann (13) have concluded that with respect to the deposition of the inorganic constituents of its bones the normal human fetus may be regarded as entirely parasitic on the maternal organism, since large differences in calcium and phosphorus intake by the mothers did not seem to affect the degree of calcification of the tibiae of the new-born. Although the growth of the fetus during the first half of gestation proceeds at a rapid rate, the actual weight of the human fetus is inappreciable when compared with that of the mother, its weight scarcely approximating 50 gm. by the end of the 4th month. It is not, however, until in the last half of pregnancy that a sacrifice on the part of the mother becomes apparent in either activity or body substance. Indeed, this period is characterized by an extraordinarily rapid accretion of tissue for the fetus has increased to a weight varying from 1497 to 3348 gm. at term.
There are wide fluctuations in the total mineral content of individual fetuses within a given age range. Chart 2 illustrates these fluctuations in the total ash content of 69 individual human fetuses at different ages. Furthermore, the average growth curve demonstrates a greatly augmented demand for minerals during the last 2 or 3 months of intrauterine life. The fetus contains on the average only 0.55 gm. of ash by the end of the 4th month, whereas at maturity it may possess from 54 to 112 gm.
The average percentage of ash in the dry fetus rises from 9.7 per cent at the 3rd month to 17.4 per cent at the 6th month, after which it gradually drops to 10 per cent by maturity. The total mineral content in the wet fetus increases gradually from 0.73 per cent in the 3rd month to 2.79 per cent at term.
The calcium stored up by the human embryo through the first 4 months of growth averages a little more than 0.1 gm., an inappreciable amount when compared with the 13 to 33 gm. of calcium fixed in the fetal tissues during the succeeding months. The actual calcium content of 69 human fetuses is graphically plotted according to age in Chart 3. Not only is the absolute calcium in

![Chart 4](http://www.jbc.org/)
our individual cases and those from the literature given, but the average calcium composition at the different age levels is shown. The number of cases used in obtaining the average curve of growth is given in circles. It is noted that the greatest calcium deposition is made in the last 3 months of fetal life. This is significant when it is recognized that maternal reserves of calcium may become depleted in the last part of gestation as is evidenced by the breaking down or loss of teeth of the mother during or immediately following the termination of pregnancy (14). The percentage of calcium in the total ash of the fetus increases rapidly up through the 4th month and thereafter it remains remarkably constant, varying only between 26.8 and 27.4 per cent. This would indicate that the calcium composition of growth of the fetus is the same during the last months of intrauterine development.

The magnesium per individual and its average composition in forty-six human fetuses are given in Chart 4. The magnesium in toto of the fetus at 4 months averages 0.028 gm., whereas at maturity it approximates only 0.5 gm. The average content of magnesium shows an increased utilization up to the 8th month. Since the average composition curve of magnesium is greatly influenced by the large amount of magnesium found in Case 19, it is of importance to note that this premature specimen was one of a pair of twins and lived for 4 days after birth. The food intake and treatment during extrauterine life possibly contributed to its high mineral content. It may be noted that the average percentage of magnesium in the total ash decreases slightly with the age of the embryo.

Robertson (15) has shown that growth in weight or linear dimensions does not proceed with uniformly retarded or accelerated velocity from the moment of its inception until the period of its completion. On the contrary, growth takes place relatively slowly, then more rapidly, and again more slowly, thus yielding an S-shaped curve of growth designated as a growth cycle. Two or three of these sigmoid curves may be superimposed upon one another in the complete growth of an individual. One cycle of man has its inception during the intrauterine growth subsequent to implantation of the embryo and is interrupted by birth when it is not yet half completed and culminates towards the end of the 1st year of postnatal life. The curves illustrating the storage of
minerals in the fetus show the first phase of this sigmoid type curve (Charts 2 to 4). They indicate, furthermore, that in so far as the mother is concerned, the greatest mineral drain on her tissues comes during the last 3 months of gestation, for the fetal demand itself is insignificant up to this time. From the data available, the average monthly increments of the fetus from the 2nd to the 10th months respectively are 0.07, 0.48, 2.64, 6.47, 4.71, 12.12, 12.80, and 41.96 gm. of ash; 0.01, 0.11, 0.83, 1.71, 0.98, 3.16, 3.54, and 12.1 gm. of calcium. It is important that during the last months of pregnancy the mother should demand the best available medical supervision and should follow rigidly the dictum of sound nutritional principles in order that her own body tissues may be preserved and at the same time give to her unborn child materials of sufficient quality and quantity to satisfy optimal growth requirements.

**SUMMARY**

Twenty-five human fetuses, ranging from 9 to 40 cm. in length and consequently varying from 2 to 8 lunar months in age, have been dried, ashed, and analyzed for calcium and magnesium. These results have been summarized and interpreted together with those in the literature.

The analyses of 96 human fetuses have been used in constructing growth diagrams. By means of a semilogarithmic chart it is demonstrated that the length of the body increases very rapidly during the first 4 or 5 months in utero, after which the rate decreases. By the same method it is shown that the fetal demand for total ash, total solids, and calcium increases progressively and at approximately the same rate with age during intrauterine life, whereas magnesium increases at a slower and different rate.

Up to the 4th month the mineral requirement of the fetus approximates in toto 0.55 gm. of ash, 0.1 gm. of calcium, and 0.028 gm. of magnesium, whereas by maturity the quantities used up are from 54 to 112 gm. of ash, 13 to 33 gm. of calcium, and 0.277 to 0.78 gm. of magnesium.

The total ash varies from 4 to 21 per cent of the dry body weight. Calcium represents from 6 to 30 per cent of the total mineral content of the body, while magnesium is present in only 0.6 to 0.9 per cent of the total ash.
The greatest fetal demand for minerals comes during the last 3 months of gestation. Whether or not the requirements of the fetus can be met from the mother’s food intake is being investigated further.¹

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¹ These studies are being carried forward in the Research Laboratory of the Children’s Fund of Michigan, Detroit.
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