

OBSERVATIONS ON THE CAPACITY OF THE STOMACH IN THE FIRST TEN DAYS OF POSTNATAL LIFE

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In the transition from intrauterine to extrauterine life few organs of the body are more affected than the stomach. The change influences many characters of the organ's morphology, and the position, the mass, the finer structure, and particularly the capacity are rapidly modified and adjusted to the new conditions and functions of postnatal life.

The changes in gastric capacity in this period of transition have not been studied very intensively. As early as 1856 Guillot¹ published some data regarding physiologic gastric capacity in the first few days of extrauterine life and this was followed somewhat later by a more extensive study by Bouchaud.² Since that time further information on the subject has been published by Hillebrand,³ Kruger,⁴ Ssnitkin,⁵ Cammerer,⁶ Tuley,⁷ Jaschke,⁸ Landois⁹ and others. The figures presented in most of these studies are not extensive, and are usually incidental to more general studies of metabolism in the neonatal period. Much of the early work is no longer of more than historic value because the observations were made under conditions

1. Guillot, N.: De la nourrice et du nourrisson, *Union méd.*, 1852, p. 61.

2. Bouchaud: De la mort par inanition et études expérimentales sur la nutrition chez le nouveau-né, Thèse, Paris, 1864.

3. Hillebrand, F.: Untersuchungen über Milchzufuhr und über die Jodkaliumausscheidung des Säuglings, *Arch. f. Gynäk.* **15**:453, 1885.

4. Krüger, G.: Ueber die zur Nahrung Neugeborener erforderlichen Milchmengen mit Rücksicht auf die Gewichtsveränderungen der Kinder, *Arch. f. Gynäk.* **7**:59, 1875.

5. Ssnitkin, N.: (The Quantity of Breast-Milk Consumed by Sucklings), *Allg. med. Centr. Ztg.* **45**:317, 1876.

6. Cammerer, W.: Der Stoffwechsel eines Kindes im ersten Lebensjahr, *Ztschr. f. Biol.* **14**:383, 1878.

7. Tuley, H. E.: Observations on the Capacity of the Stomachs of Infants Under Ten Days of Age, *Arch. Pediat.* **10**:423, 1893.

8. Jaschke, R. T.: Neue Erfahrungen in der Technik der Ernährung sowie zur Physiologie und Pflege des Neugeborenen, *Monatschr. f. Geburtsh. u. Gynäk.* **35**:60, 1912.

9. Landois, F.: Zur Physiologie des Neugeborenen, *Monatschr. f. Geburtsh. u. Gynäk.* **22**:194, 1905.

which no longer obtain in modern infant feeding. Regarding anatomic capacity in this period, we have still less accurate information, the only extensive series of measurements being that of Alliot¹⁰ on newborn children.

It has been pointed out recently that, during the greater part of the suckling period, there exists a fairly definite and constant relation between the anatomic capacity of the stomach, as determined post-mortem, and the physiologic capacity as ascertained by weighing the child before and after feeding.¹¹ And it has been found that the capacity of the stomach increases at a very definite rate in early life despite the numerous fluctuations due to differences in physical constitution and to varying physiologic factors. It is the purpose of the present paper to trace the changes which these measures of gastric capacity undergo in the neonatal period, to ascertain the main factors which influence them, and to determine, in as far as possible, how soon after birth the relations and the rate of growth in capacity which are characteristic of the suckling period are established.

Through the kindness of Dr. J. P. Sedgwick, chief of the department of pediatrics, we have had access to the records of the Pediatric Section of the Elliot Memorial Hospital of the University of Minnesota. From these we have taken the records of the amount of individual feedings, as determined by weighing before and after nursing, of 323 children during the first ten days of life. In all we secured 14,571 individual records of physiologic gastric capacity as determined by this method. The distribution of these records according to days and to the birth weights of the individuals observed is shown in Table 1. To avoid confusion we have not included a statement of the number of cases in later tables but this record can be ascertained in all cases by reference to Table 1.

Our study was limited to children having a birth weight of 2,000 gm. or over, and no twins were included in the group. Otherwise the cases were taken seriatim from the hospital records. In this group there were 187 males and 136 females. The average weight at birth of the males was 3,349 gm. and of the females 3,254 gm. These figures are somewhat below the averages determined by Taylor¹² in his study of the new-born of this same clinic, but this discrepancy is probably due to the fact that Taylor, desiring to establish a norm for full term children, excluded, as far as possible, all prematures.

10. Alliot, L.: *La capacité stomacale du nouveau-né*, Thèse, Paris, 1905.

11. Scammon, R. E.: Some Graphs and Tables Illustrating the Growth of the Human Stomach, *Am. J. Dis. Child.* **17**:395 (May) 1919.

12. Taylor, R.: The Measurements of 250 Full-Term, New-Born Children, *Am. J. Dis. Child.* **17**:353 (April) 1919.

The average weight of the new-born in this same clinic as determined by Ramsey and Ally,¹³ studying 300 cases, was 3,391 gm. for males and 3,276 gm. for females.

The children were breast fed five times per day, but many babies did not secure their full quota of feedings on the first day as is indicated by the small totals both of cases and feedings in column 2 of Table 1. After the first day the number of missed feedings was negligible.

TABLE 1.—MATERIAL USED IN THE STUDY OF PHYSIOLOGIC GASTRIC CAPACITY *

| Age in Days | Number of Cases and Number of Feedings | | | | | All Cases (Aver. 3,315 Gm.) |
|--------------------|---|--|---|--|--|--------------------------------|
| | Group I 2,000 to 2,500 Gm. Birth-Weight (Aver. 2,280 Gm.) | Group II 2,500 to 3,000 Gm. Birth-Weight (Aver. 2,840 Gm.) | Group III 3,000 to 3,500 Gm. Birth-Weight (Aver. 3,246 Gm.) | Group IV 3,500 to 4,000 Gm. Birth-Weight (Aver. 3,731 Gm.) | Group V 4,000 Gm. and Above Birth-Weight (Aver. 4,143 Gm.) | |
| 1 | 5 (10) | 32 (74) | 71 (154) | 31 (63) | 14 (63) | 153 (364) |
| 2 | 14 (65) | 63 (311) | 143 (698) | 75 (370) | 28 (135) | 323 (1,579) |
| 3 | 14 (70) | 63 (308) | 143 (713) | 75 (371) | 28 (136) | 323 (1,598) |
| 4 | 14 (70) | 63 (313) | 143 (713) | 75 (374) | 28 (139) | 323 (1,609) |
| 5 | 14 (69) | 63 (315) | 143 (712) | 75 (373) | 28 (138) | 323 (1,607) |
| 6 | 14 (70) | 63 (314) | 143 (714) | 75 (373) | 28 (138) | 323 (1,609) |
| 7 | 14 (70) | 63 (313) | 143 (714) | 75 (373) | 28 (138) | 323 (1,608) |
| 8 | 14 (70) | 63 (315) | 142 (710) | 74 (370) | 28 (140) | 321 (1,605) |
| 9 | 14 (70) | 63 (314) | 141 (700) | 74 (368) | 28 (138) | 320 (1,590) |
| 10 | 14 (62) | 59 (279) | 135 (614) | 71 (331) | 28 (116) | 307 (1,402) |
| Total No. Feedings | (626) | (2,856) | (6,442) | (3,366) | (1,281) | (14,571) |

* The upper figures represent the number of cases; the lower figures, in parentheses, indicate the number of feedings.

From these data was determined the average physiologic capacity, the average maximum physiologic capacity, the average capacity in per cent. of the body weight at birth, the average maximum capacity in per cent. of the body weight at birth, the average and average maximum capacity in first born and later children, the excess of the average maximum capacity over the average capacity, and the percentage increment of the average capacity and the average maximum capacity. These determinations were made for each day of the period under consideration, first for the entire series of cases and later for the same cases grouped into five classes according to birth weight.

13. Ramsey, W. R., and Alley, A. G.: Observations on the Nutrition and Growth of New-Born Infants. *Am. J. Dis. Child.* **15**:408 (June) 1918.

The average deviation and the average percentage deviation was determined for the average capacity in the group of cases having a birth weight ranging from 3,000 to 3,500 gm. The average and average maximum capacity in males and in females was also determined in this group.

Average physiologic capacity.—The average physiologic capacity, for all children having a birth weight of 2,000 gm. or over is shown in the seventh column of Table 2 and the curve labeled "B" in Figure 1 illustrates it graphically. The average physiologic capacity of such children as received feedings on the first day was 7 gm. This was almost doubled on the second day (13 gm.) and almost quadrupled on the third day (27 gm.). On the fourth day the average capacity was a little more than six times that of the first day (46 gm.). After the fourth day the increase in average capacity was much less rapid, although it was still continued, and on the tenth day it was 81 gm., or about eleven and one-half times that of the first day. As these figures indicate, a curve of the average capacity in the first ten days (Curve B, Figure 1) shows two distinct segments. During the period from birth to the fifth day it rises rapidly, thereafter it is continued upward at a much less rapid rate.

TABLE 2.—AVERAGE CAPACITY OF THE STOMACH IN THE FIRST TEN DAYS OF POSTNATAL LIFE

| Days | Average Physiologic Capacity (Gm.) | | | | | |
|------|------------------------------------|--------------------|--------------------|--------------------|-------------------|--------------------------------|
| | Cases Having a Birth-Weight of | | | | | All Cases of 2,000 Gm. or More |
| | 2,000 to 2,500 Gm. | 2,500 to 3,000 Gm. | 3,000 to 3,500 Gm. | 3,500 to 4,000 Gm. | 4,000 Gm. or More | |
| 1 | 5 | 6 | 6 | 8 | 5 | 7 |
| 2 | 10 | 13 | 13 | 14 | 11 | 13 |
| 3 | 22 | 27 | 27 | 27 | 26 | 27 |
| 4 | 36 | 42 | 45 | 51 | 46 | 46 |
| 5 | 43 | 53 | 57 | 62 | 59 | 57 |
| 6 | 43 | 59 | 64 | 72 | 70 | 64 |
| 7 | 48 | 60 | 67 | 76 | 79 | 68 |
| 8 | 51 | 66 | 71 | 78 | 80 | 71 |
| 9 | 55 | 68 | 75 | 88 | 87 | 76 |
| 10 | 60 | 72 | 79 | 90 | 96 | 81 |

Average maximum physiologic capacity.—In this study the average maximum physiologic capacity has been determined by adding the sums of the largest meal ingested by each child of the series on a given day and dividing the result by the number of cases. This is a somewhat different measurement from that employed by Feer¹⁴ and by Scammon,¹¹ who used the maximum meal of a given week as a basis for determining the average maximum. The value as determined by the above definition is shown in Table 3 and is represented graphically by curve "A" in Figure 1.

14. Feer, E.: Beobachtungen über die Nahrungsmengen von Brustkindern, Jahrb. f. Kinderh. 42:195, 1896.

Examining these figures and the graph it is seen that there is a close relationship between average and average maximum capacity. The average maximum capacity on the first day is 9 gm. This is more than doubled on the second day (22 gm.) and increases nearly fivefold on the third day (43 gm.). On the fourth day it is a little more than seven times as great as on the first day. Thereafter, as in the case of the average capacity, the gain is much slower and on the tenth day it is eleven and two-thirds times that of the first day, or 105 gm.

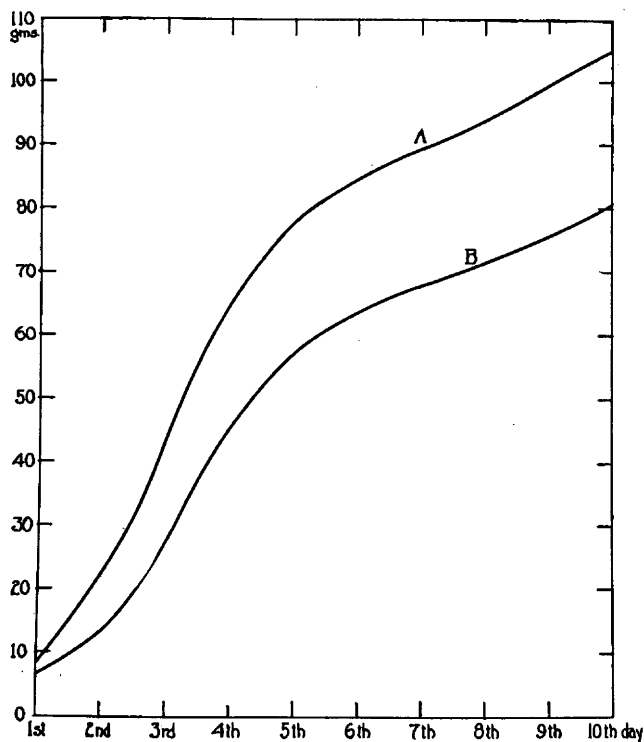


Fig. 1.—A graph showing the physiologic capacity of the stomach in the first ten days of postnatal life. A, curve of average maximum physiologic capacity; B, curve of average physiologic capacity. Based on all cases having a birth weight of 2,000 gm. or more.

The curve illustrating the changes in average maximum capacity (Curve A, Figure 1) is almost a duplicate of that of the average capacity, although all of the values are somewhat greater. It shows the same two phases as does the curve of average capacity.

Relative average and average maximum physiologic capacity.—Some interesting results are obtained if the average physiologic capacity and the average maximum capacity are calculated in terms

TABLE 3.—AVERAGE MAXIMUM PHYSIOLOGIC CAPACITY OF THE STOMACH IN THE TEN DAYS OF POSTNATAL LIFE

| Days | Average Maximum Physiologic Capacity (Gm.) | | | | | |
|------|--|--------------------|--------------------|--------------------|-------------------|--------------------------------|
| | Cases Having a Birth-Weight of | | | | | All Cases of 2,000 Gm. or More |
| | 2,000 to 2,500 Gm. | 2,500 to 3,000 Gm. | 3,000 to 3,500 Gm. | 3,500 to 4,000 Gm. | 4,000 Gm. or More | |
| 1 | 7 | 9 | 9 | 10 | 6 | 9 |
| 2 | 18 | 22 | 23 | 24 | 19 | 22 |
| 3 | 35 | 41 | 43 | 45 | 44 | 43 |
| 4 | 53 | 60 | 65 | 71 | 65 | 65 |
| 5 | 58 | 70 | 78 | 85 | 85 | 78 |
| 6 | 63 | 78 | 86 | 94 | 88 | 85 |
| 7 | 64 | 82 | 91 | 98 | 100 | 90 |
| 8 | 65 | 86 | 94 | 105 | 100 | 94 |
| 9 | 81 | 87 | 99 | 107 | 114 | 99 |
| 10 | 84 | 92 | 104 | 115 | 122 | 105 |

TABLE 4.—AVERAGE PHYSIOLOGIC CAPACITY OF THE STOMACH IN THE TEN DAYS OF POSTNATAL LIFE, CALCULATED IN PER CENT. OF THE BODY WEIGHT AT BIRTH

| Days | Average Physiologic Capacity in Per Cent. of the Body-Weight at Birth | | | | | |
|------|---|--------------------|--------------------|--------------------|-------------------|--------------------------------|
| | Cases Having a Birth-Weight of | | | | | All Cases of 2,000 Gm. or More |
| | 2,000 to 2,500 Gm. | 2,500 to 3,000 Gm. | 3,000 to 3,500 Gm. | 3,500 to 4,000 Gm. | 4,000 Gm. or More | |
| 1 | 0.23 | 0.23 | 0.22 | 0.23 | 0.13 | 0.21 |
| 2 | 0.44 | 0.45 | 0.39 | 0.38 | 0.26 | 0.39 |
| 3 | 0.97 | 0.94 | 0.83 | 0.74 | 0.63 | 0.81 |
| 4 | 1.61 | 1.47 | 1.40 | 1.38 | 1.11 | 1.38 |
| 5 | 1.92 | 1.87 | 1.76 | 1.66 | 1.43 | 1.72 |
| 6 | 1.90 | 2.08 | 1.97 | 1.93 | 1.69 | 1.95 |
| 7 | 2.12 | 2.12 | 2.07 | 2.05 | 1.91 | 2.06 |
| 8 | 2.26 | 2.33 | 2.18 | 2.09 | 1.93 | 2.16 |
| 9 | 2.45 | 2.40 | 2.31 | 2.23 | 2.10 | 2.28 |
| 10 | 2.66 | 2.52 | 2.42 | 2.42 | 2.33 | 2.43 |

TABLE 5.—AVERAGE MAXIMUM PHYSIOLOGIC CAPACITY OF THE STOMACH IN THE FIRST TEN DAYS OF POSTNATAL LIFE, CALCULATED IN PERCENTAGES OF THE BODY WEIGHT AT BIRTH

| Days | Per Cent. of Body-Weight | | | | | |
|------|--------------------------------|--------------------|--------------------|--------------------|-------------------|--------------------------------|
| | Cases Having a Birth-Weight of | | | | | All Cases of 2,000 Gm. or More |
| | 2,000 to 2,500 Gm. | 2,500 to 3,000 Gm. | 3,000 to 3,500 Gm. | 3,500 to 4,000 Gm. | 4,000 Gm. or More | |
| 1 | 0.29 | 0.32 | 0.27 | 0.28 | 0.14 | 0.27 |
| 2 | 0.80 | 0.79 | 0.70 | 0.64 | 0.47 | 0.68 |
| 3 | 1.54 | 1.46 | 1.31 | 1.22 | 1.06 | 1.29 |
| 4 | 2.35 | 2.13 | 2.00 | 1.92 | 1.57 | 1.96 |
| 5 | 2.57 | 2.46 | 2.40 | 2.28 | 2.06 | 2.35 |
| 6 | 2.80 | 2.75 | 2.65 | 2.53 | 2.14 | 2.53 |
| 7 | 2.84 | 2.89 | 2.79 | 2.63 | 2.42 | 2.73 |
| 8 | 2.87 | 3.05 | 2.90 | 2.80 | 2.42 | 2.85 |
| 9 | 3.59 | 3.08 | 3.06 | 2.87 | 2.75 | 2.99 |
| 10 | 3.71 | 3.25 | 3.22 | 3.08 | 2.95 | 3.17 |

of the body weight at birth. These figures are shown in Tables 4 and 5 and the curves shown in Figure 2 are their graphic expression. The average gastric capacity in the first day is equal to about one-fifth of one per cent. of the body weight. By the second day this has risen to about 0.8 per cent. and on the fourth day to nearly 1.4 per cent. of the birth weight. After the fourth day the relative gastric capacity, like the actual average capacity, increases more slowly. By the tenth day the average capacity is equal to about 2.4 per cent.

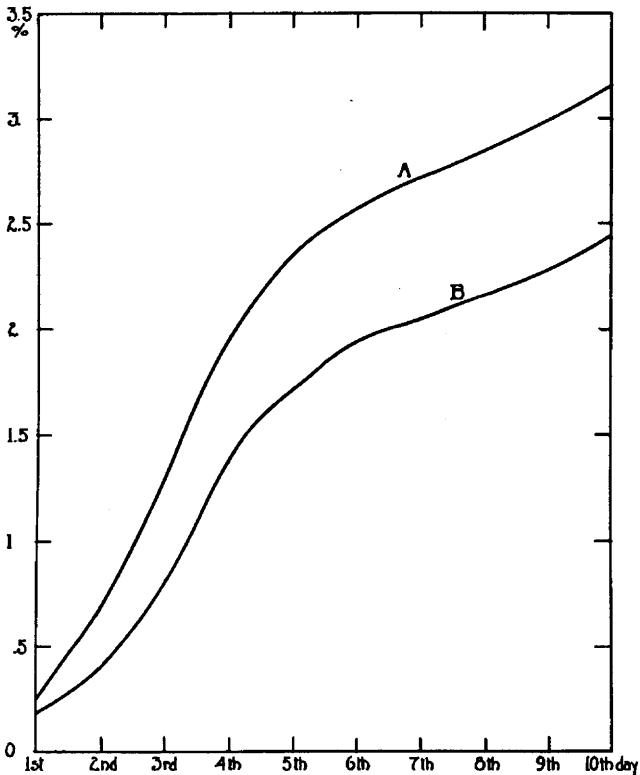


Fig. 2.—A graph showing the physiologic capacity of the stomach in the first ten days of postnatal life, as determined in per cent. of the body weight at birth. A, relative average maximum physiologic capacity; B, relative average physiologic capacity. Based on all cases having a birth weight of 2,000 gm. or more.

of the body weight at birth or about twelve times more than the average capacity on the first day.

The changes in the relative average maximum capacity are very similar to those in the relative average capacity. Starting at 0.27 per cent. on the first day, the relative average maximum rises rapidly

to nearly 2 per cent. by the fourth day. Thereafter the amount increases much more slowly up to the tenth day, when it stands at nearly 3.2 per cent.

The curves based on these figures are much alike and are quite similar to those of the average and the average maximum capacity. They show the same characteristics of the rapid initial rise until the fourth day and the slower elevation from that point to the end of the period of observation (Fig. 2).

Relation between body weight and physiologic capacity.—The results which have been presented are based upon the study of the

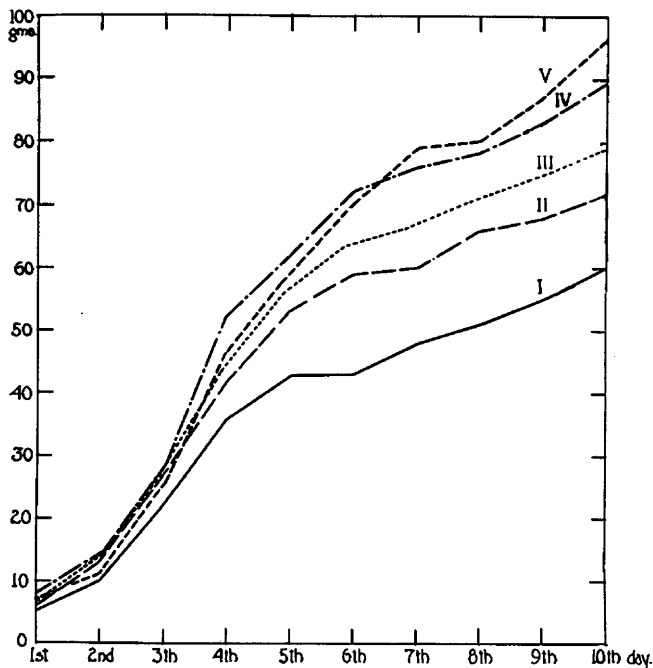


Fig. 3.—Average physiologic gastric capacity in the first ten days of post-natal life, in groups of children arranged according to birth weight. Curve I, average capacity of children with a birth weight of from 2,000 to 2,500 gm. Curve II, average capacity of children with a birth weight of from 2,500 to 3,000 gm. Curve III, average capacity of children with a birth weight of from 3,000 to 3,500 gm. Curve IV, average capacity of children with a birth weight of from 3,500 to 4,000 gm. Curve V, average capacity of children with a birth weight of 4,000 gm. or more.

entire series of cases having a body weight of 2,000 gm. or over. The same data were studied further by arranging the cases into groups according to body weight at birth. Five of these groups were established: Group I, from 2,000 to 2,500 gm.; Group II, from 2,500 to 3,000 gm.; Group III, from 3,000 to 3,500 gm.; Group IV, from 3,500

to 4,000 gm. and group V, 4,000 gm. and over. The results obtained by this procedure are shown in Tables 2, 3, 4 and 5, and by the curves shown in Figures 3, 4, 5 and 6.

The absolute average gastric capacity evidently increases with the body weight in Groups I, II, III and IV (children weighing between 2,000 and 4,000 gm.). As will be seen in Table 2 and in Figure 3,

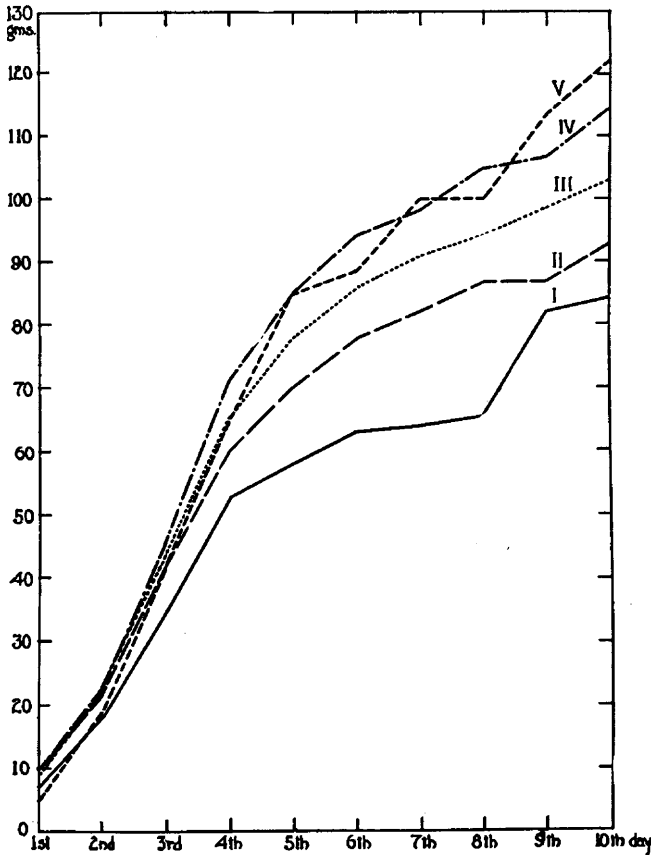


Fig. 4.—Average maximum physiologic gastric capacity in the first ten days of postnatal life, in groups of children arranged according to birth weight. Curve I, children having a birth weight of from 2,000 to 2,500 gm. Curve II, children having a birth weight of from 2,500 to 3,000 gm. Curve III, children having a birth weight of from 3,000 to 3,500 gm. Curve IV, children having a birth weight of from 3,500 to 4,000 gm. Curve V, children having a birth weight of from 4,000 gm. or more.

there is a slight difference in favor of the groups of heavier children even on the first day and this becomes more noticeable in the latter part of the period. Group V (children having a birth weight of 4,000 gm. or over) shows a somewhat different condition. During the

first three days of postnatal life the average capacity in these infants is slightly below that of the other groups of children and is only a little more than that of Group I (weighing from 2,000 to 2,500 gm.). However, the capacity of the heaviest group rises rapidly on the fourth and fifth days and on the sixth day and thereafter it exceeds that of any of the other groups.

The absolute average maximum capacity shows relations similar to those just described. It rises with the birth weight in all groups under 4,000 gm., but Group V (of 4,000 gm. and over) shows the

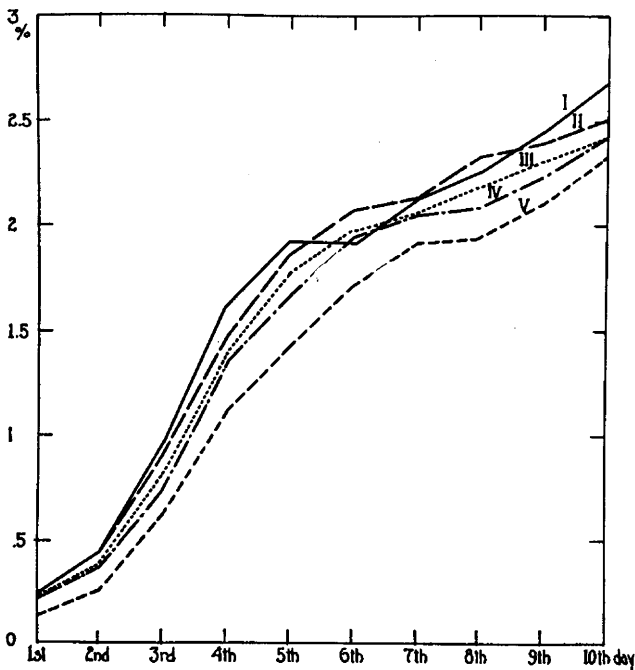


Fig. 5.—A graph illustrating the relative average physiologic gastric capacity in the first ten days of postnatal life in groups of children arranged according to birth weight. Curve I, children having a birth weight of from 2,000 to 2,500 gm. Curve II, children having a birth weight of from 2,500 to 3,000. Curve III, children having a birth weight of from 3,000 to 3,500 gm. Curve IV, children having a birth weight of from 3,500 to 4,000 gm. Curve V, children having a birth weight of 4,000 gm. or over.

lowest average maximum capacity on the first day. It is not until the ninth day that this value is greater in the heaviest than in the lighter groups of children.

The figures on the *relative* physiologic capacity, i. e., the capacity as calculated in per cent. of the birth weight, show relations which are quite different from those of absolute physiologic capacity.

On the first day the relative average capacity is approximately the same in all groups of children having a birth weight under 4,000 gm. Thereafter, with one minor exception, the relative capacity is always greater in the lighter than the heavier groups. This difference, although not very great, is practically always present. The children

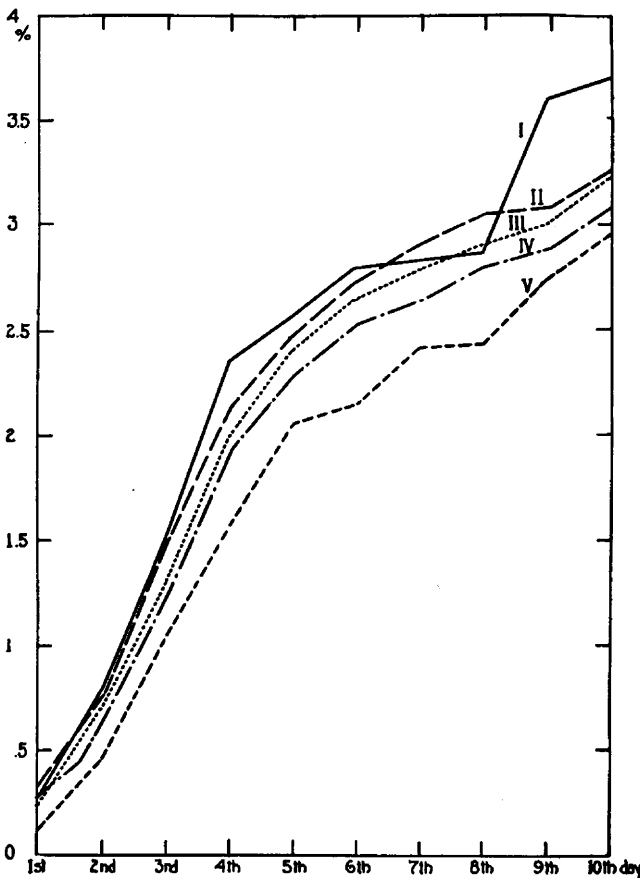


Fig. 6.—A graph illustrating the relative average maximum physiologic gastric capacity in the first ten days of postnatal life in groups of children arranged according to birth weight. Curve I, children having a birth weight of from 2,000 to 2,500 gm. Curve II, children having a birth weight of from 2,500 to 3,000 gm. Curve III, children having a birth weight of from 3,000 to 3,500 gm. Curve IV, children having a birth weight of from 3,500 to 4,000 gm. Curve V, children having a birth weight of 4,000 gm. or over.

of Group V (of 4,000 gm. and over) have a relative capacity only a little over one-half as great as that of the lighter groups and the average value always remains far below that of the other groups during the period of observation (Fig. 5).

The history of the relative maximum capacity is similar to that of the relative average capacity. The general rule that the smaller the birth weight of the group the larger the relative capacity holds true throughout except for the first day, when the relative maximum capacity is about the same in all groups of children under 4,000 gm. in weight, and for the eighth day, when this value in Group I (from 2,000 to 2,500 gm. in weight) falls below that of Group II (from 2,500 to 3,000 gm. in birth weight).

It may, therefore, be concluded that while the heavier children of this series tend to have a larger absolute physiologic capacity than do the lighter ones, this capacity does not increase directly in proportion with body size.

TABLE 6.—DIFFERENCES IN THE AVERAGE PHYSIOLOGIC GASTRIC CAPACITIES OF FIRST-BORN AND LATER CHILDREN *

| Days | Differences in Capacities (Gm.) | | | | | |
|------|---------------------------------|--------------------|--------------------|--------------------|-------------------|--------------------------------|
| | Cases Having a Birth-Weight of | | | | | All Cases of 2,000 Gm. or More |
| | 2,000 to 2,500 Gm. | 2,500 to 3,000 Gm. | 3,000 to 3,500 Gm. | 3,500 to 4,000 Gm. | 4,000 Gm. or More | |
| 1 | +1 | -1 | +1 | +6 | +6 | 0 |
| 2 | 0 | +6 | -3 | +4 | +7 | +2 |
| 3 | 0 | +9 | -5 | +4 | +15 | +3 |
| 4 | 0 | +6 | +1 | +12 | +23 | +5 |
| 5 | -4 | +3 | -4 | +3 | +6 | -1 |
| 6 | +7 | -1 | -10 | -2 | +17 | -1 |
| 7 | +5 | -4 | -13 | +2 | +20 | 0 |
| 8 | +8 | -3 | -8 | +3 | +19 | 0 |
| 9 | -2 | -2 | -5 | +2 | +34 | +8 |
| 10 | -13 | +4 | -3 | 0 | +18 | +3 |

* Figures preceded by a minus sign indicate a greater average capacity in first born children. Figures preceded by a plus mark indicate a greater average capacity in later children.

Physiologic capacity in first-born and later children.—The average and the relative average physiologic capacity were calculated separately for first-born and for later children. This was done first for the entire series of cases and then for the several groups arranged according to birth weight. The differences between the first born and later children were then determined from these figures and are shown in Table 6. The figures in this table which are preceded by a plus sign indicate an excess in capacity of the later children over the first born, and those preceded by a minus, an excess in capacity of the first born over the later born. If Groups I to IV, inclusive, of this table are examined, it will be seen that there are no consistent differences in these values in the two classes of children. However, in Group V, having a birth weight of 4,000 gm. or over, the capacities of later children are consistently and considerably greater than those of first born infants. As the relative average capacities showed practically identical results they will not be considered here in detail.

Physiologic capacity in males and females.—The average and the average maximum capacities were determined separately for males and for females in Group III (children having a birth weight of from 3,000 to 3,500 gm.). No consistent sex difference in capacity, as determined by either of these measures, was observed.

Variability in average physiologic capacity in the neonatal period.—It is, of course, well known that the variation in the amounts ingested at single meals by young infants is very great, but apparently no attempt has been made to measure it. In order to secure some measure of this value we determined the range of variation and the average deviation and the percentage deviation in the feeding records of the group of children having a birth weight ranging from 3,000 to 3,500 gm. (Group III).

The range of variation is easily secured by determining the maximum and minimum meal of the entire series of feeding records for each day of the period of observation. This determination, while of interest, tells us little of the actual amount of variation in our material, which is much better indicated by the average deviation and the percentage deviation. The average deviation is calculated by first determining the amount that each observation differs from the average of the whole series. These amounts are then added (plus and minus signs being disregarded) and the sum is divided by the total number of cases. The result expresses the average deviation (in this case in grams). This value can be readily converted into a per cent. of the average capacity by dividing by the average of all cases and multiplying by 100.

TABLE 7.—VARIABILITY IN AVERAGE PHYSIOLOGIC GASTRIC CAPACITY IN THE FIRST TEN DAYS OF POSTNATAL LIFE *

| Days | Number of Observations | Average Capacity, Gm. | Minimum Feeding, Gm. | Maximum Feeding, Gm. | Average Deviation, Gm. | Per Cent. Deviation |
|------|------------------------|-----------------------|----------------------|----------------------|------------------------|---------------------|
| 1 | 154 | 6 | 3 | 60 | 3.6 | 60.0 |
| 2 | 698 | 13 | 4 | 80 | 6.8 | 52.3 |
| 3 | 713 | 27 | 3 | 110 | 15.2 | 56.3 |
| 4 | 713 | 45 | 5 | 130 | 17.9 | 39.8 |
| 5 | 712 | 57 | 8 | 140 | 19.2 | 34.7 |
| 6 | 714 | 64 | 2 | 165 | 19.3 | 30.1 |
| 7 | 714 | 67 | 10 | 145 | 20.6 | 30.7 |
| 8 | 710 | 71 | 10 | 160 | 21.3 | 30.0 |
| 9 | 700 | 75 | 5 | 148 | 20.5 | 27.3 |
| 10 | 614 | 79 | 10 | 210 | 20.6 | 26.0 |

* Based upon the feeding records of children with a birth-weight ranging from 3,000 to 3,500 grams.

The results of these calculations are shown in Table 7 and are, in part, graphically expressed in Figure 7. The minimum meal during the first ten days ranges from 2 to 10 gm. and shows no particular regularity. The maximum meal was 60 gm. on the first day and rises

fairly steadily to 160 gm. on the sixth day. Thereafter it is quite irregular. The average deviation rises rapidly in the first three or four days, but after the fourth day it stands between 19.2 and 21.3 gm., which is surprisingly constant considering the nature of the material. The percentage deviation in the first three days of post-natal life forms over one-half of the average capacity. It then decreases, at first rapidly and later quite slowly, during the remainder of the period. In round numbers the percentage variability in the

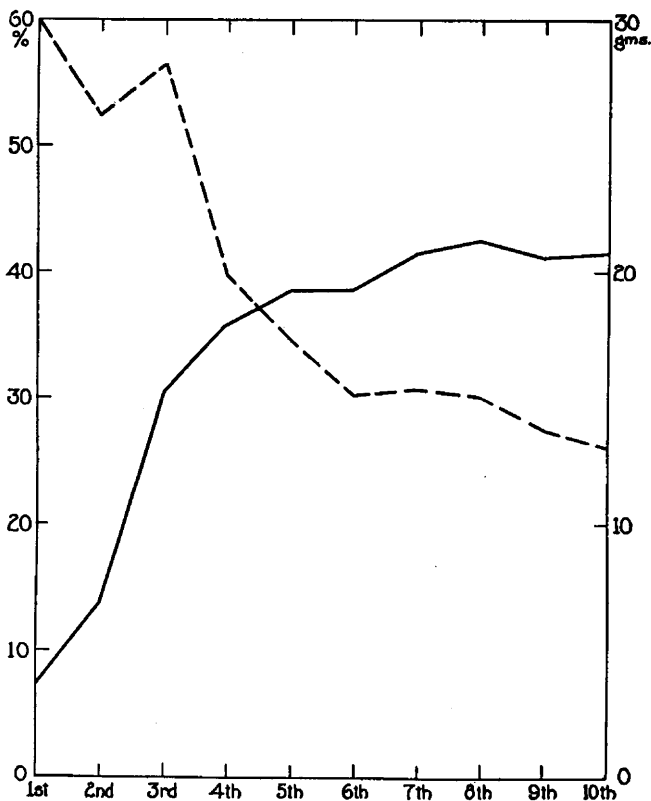


Fig. 7.—A graph illustrating the changes in variability in average physiologic gastric capacity in the first ten days of postnatal life. Curve A (in solid line), average deviation in average physiologic capacity. Curve B (in broken line), percentage deviation in average physiologic capacity. Based on the feeding records of a group of 143 children having a birth weight ranging from 3,000 to 3,500 gm.

first third of the period of observation is twice as great as in the last third.

This variability seems to have no close relation to the feeding schedule of the children. The maximum meal of the day may occur at any of the five feeding periods. In the first four days it is less

frequently the first meal in the morning, while in the last six days the last meal in the evening is less often the largest one of the day. However, the differences in distribution of the maximum meal among the several feeding periods in the entire group of cases are so slight that no definite conclusion can be drawn from them.

In our entire series of cases there were forty-six instances in which a meal was missed. In eighteen cases the succeeding meal was smaller than the average; in twenty-two cases it was larger than the average, and in six cases it was the same as the average meal. The small amount of data which we have on this subject does not indicate that loss of a meal is compensated for by a larger succeeding one, in the first few days of postnatal life.

Percentage increment in physiologic capacity in the neonatal period.

—The measures of growth in gastric capacity which have been described in the preceding sections of this paper are mainly in the form of absolute quantities. A much more striking exposition of the changes is given by the daily percentage increment. This value is calculated by determining the gain in capacity for each day in per cent. of the capacity of the day preceding. The results of these calculations are shown in graphic form in curves B and C in Figure 8. The increment in average physiologic capacity is over 80 per cent. on the second day and over 100 per cent. on the third day. Thereafter, it falls rapidly to about 20 per cent. on the fourth day and to less than 10 per cent. for the last third of the period of observation. The percentage increment in maximum physiologic capacity follows much the same history although it is greater at the beginning of the period (Curve B, Fig. 8).

Relation of average physiologic capacity to average maximum physiologic capacity in the neonatal period.—In a recent paper one of us pointed out that the average maximum physiologic capacity, from the third week after birth until the seventh month, is about one-half greater than the average physiologic capacity. The relation of these two values in the period of the new-born shows several striking changes. On the second day the average maximum capacity is about 25 per cent. greater than the average capacity. On the second day it is 70 per cent. greater. It then drops until the fifth or sixth day to about one-third more than the average capacity (Curve A, Fig. 8.).

The anatomic capacity of the stomach in the new-born and the neonatal period.—The anatomic capacity of the stomach in the new-born, as determined by a number of observers using a variety of methods, falls between 25 and 35 c.c. Most of the published work on anatomic capacity at birth does not include records of the individual

cases and therefore is not very satisfactory. The most complete published data on this subject are those of Alliot,¹⁰ and to these we have been able to add a small number of personal observations. The combined data available to us are shown in Table 8. The average anatomic capacity in a series of 25 new-born children ranging in birth weight from 2,000 to 4,300 gm. was 33 cc. In thirteen premature children having a birth weight ranging from 1,200 to 2,000 gm. the average

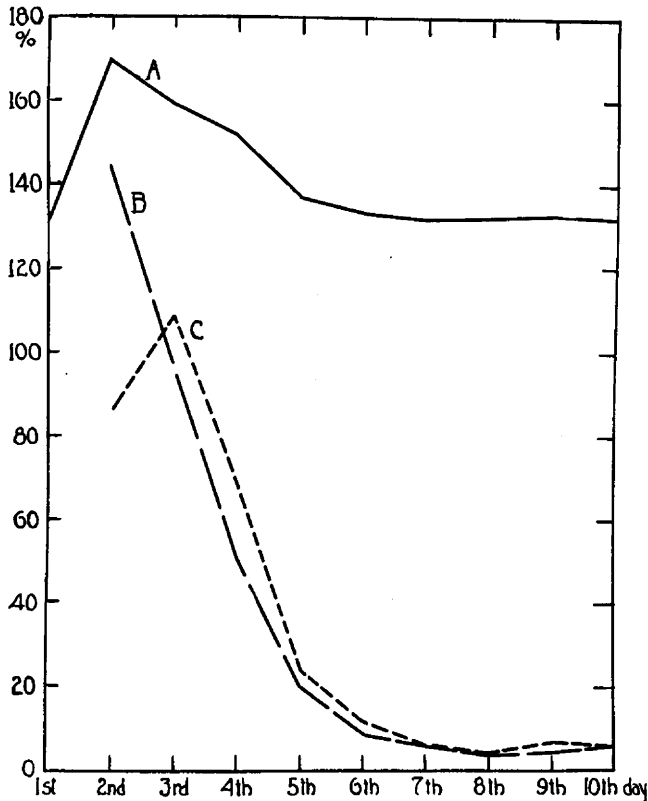


Fig. 8.—Curve A, percentage which the average maximum physiologic capacity forms of the average physiologic capacity in the first ten days of postnatal life. Based on all cases of 2,000 gm. and over. Curve B, percentage increment in the average physiologic gastric capacity in the first ten days of postnatal life. Based on all cases of 2,000 gm. and over. Curve C, percentage increment in the average maximum physiologic gastric capacity in the first ten days of postnatal life. Based on all cases of 2,000 gm. and over.

capacity was 22 c.c. In new-born children having a body weight between 2,000 and 3,000 gm. the average capacity was 30 c.c.; and in those between 3,000 and 4,000 gm. body weight, 35 c.c. Three very large infants, having a body weight of 4,000 gm. or more, had an

average capacity of 38 c.c. Thus the anatomic capacity at birth appears to increase somewhat with the body weight as does the physiologic capacity of the neonatal period.

The relative anatomic capacity, i. e., the capacity of the stomach calculated in per cent. of the body weight (c.c. considered equivalent to gm.), was, for this same series of cases, 1.3 per cent. in infants having a body weight below 2,500 gm., 1.1 per cent. in children weighing between 2,500 and 3,500 gm., and 0.9 per cent. in children weighing 3,500 gm. or more. Thus the relative anatomic capacity of the stomach decreases as the body weight increases, as does the relative physiologic capacity in the neonatal period.

TABLE 8.—AVERAGE ANATOMIC CAPACITY OF THE STOMACH IN THE NEW-BORN AS DETERMINED BY ZUCARRELLI'S METHOD

| Range of Body-Weight, Gm. | Average Body-Weight, Gm. | Number of Cases | Average Anatomic Capacity, C.c. |
|---------------------------|--------------------------|-----------------|---------------------------------|
| 1,500 to 2,000..... | 1,710 | 13 | 22 |
| 2,000 to 2,500..... | 2,140 | 3 | 30 |
| 2,500 to 3,000..... | 2,740 | 7 | 30 |
| 3,000 to 3,500..... | 3,210 | 6 | 35 |
| 3,500 to 4,000..... | 3,710 | 6 | 35 |
| 4,000 or more..... | 4,340 | 3 | 38 |
| 2,000 or more..... | 3,140 | 25 | 33 |

Detailed observations on the anatomic capacity of the stomach in the period between birth and the end of the second postnatal week are not very numerous. The average anatomic capacity of the first week, as indicated by the data of Fleischmann,¹⁵ Froloffski,¹⁶ Stössl,¹⁷ Zuccarelli¹⁸ and Rotch,¹⁹ is approximately 45 c.c. or nearly one-third more than the capacity at birth. In the second week the data collected by these same observers and by Holt,²⁰ d'Astros,²¹ Politzer,²² Muggia²³ and others, indicate that the anatomic capacity is about 75 c.c. These figures are based on determinations by a variety of methods, although the majority of observations were made with Zuccharelli's method. The curve of growth in anatomic capacity in the neonatal period is

15. Fleischmann: Klinik der Pädiatrik, Wien., 1875.

16. Froloffski: Material on the Anatomy of the Digestive Tract in Sucklings, Diss., St. Petersburg, 1876.

17. Stössl: Semiotik des Kindesalters, 1875.

18. Zuccarelli, P.: L'estomac de l'enfant, Thèse, Paris, 1894.

19. Rotch, T. M.: Pediatrics, Ed. 1, Philadelphia, 1896, p. 76 et seq.

20. Holt, L. E.: Observations on the Capacity of the Stomach in Infancy, Arch. Pediat. 7:960, 1891.

21. d'Astros: L'estomac de l'enfant; sa dilatation, Rev. de Mal. de l'enf. 12, 1894.

22. Politzer: Ideen zur Behandlung einer wissenschaftlichen Diätetik, Jahrb. f. Kinderh. 4, 1858.

23. Muggia, A.: La capacità e la posizione del ventricolo nei bambini, Giorn. d. r. Accad. di med. di Torino, Series 4 2:351, 1896.

shown in semidiagrammatic form in Figure 9. As will be seen from this figure, the anatomic capacity of the stomach appears to increase at a uniform rate throughout the period and there are no indications of two distinct phases of growth comparable with those seen in all of the graphs of physiologic capacity.

Although the growth of the anatomic capacity of the stomach in the neonatal period appears to be quite slow if compared with the growth in physiologic capacity, it is very rapid compared with the growth in fetal life. In the first week after birth the anatomic capacity increases more than it does in the entire last third of fetal life, and the absolute increase in the first two weeks of postnatal life is considerably greater than the entire prenatal growth.

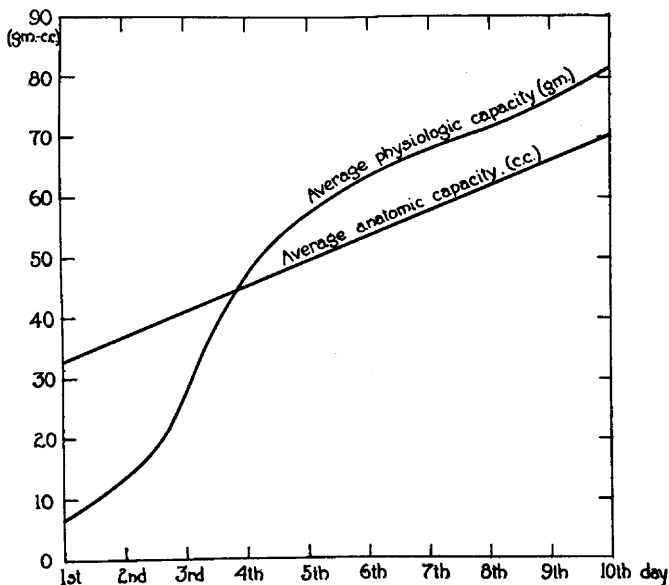


Fig. 9.—Semidiagrammatic curves illustrating the relation between the average physiologic capacity and the average anatomic capacity of the stomach in the first ten days of postnatal life.

DISCUSSION

The discussion of our data will be limited to a comparison of anatomic and physiologic capacity in the neonatal period and to a consideration of certain peculiarities of physiologic capacity during this time.

It has been pointed out by one of us (Scammon¹¹) that during the greater part of the suckling period there is a close correlation between the anatomic capacity of the stomach, as determined post-mortem, and the average physiologic capacity, as determined by weigh-

ing before and after feeding. The physiologic capacity, as determined by this method, was found to be approximately equal to the anatomic capacity of the organ under a pressure of between 15 and 20 centimeters of water. It was also noted that practically all of the techniques used in determining anatomic capacity distend the viscus to about the same extent as does a pressure of 15 centimeters of water.

The relation between anatomic and physiologic capacity in the neonatal period is somewhat more complex than in the suckling period proper. It is represented in a semidiagrammatic fashion by the two curves shown in Figure 9. At birth the anatomic capacity of the stomach is roughly four and one-half times the physiologic capacity (on the average as 33 to 7). During the first half of the first week of postnatal life the anatomic capacity increases about one-third, while the physiologic capacity is increased about six-fold. The curves of these two measures of gastric capacity therefore converge and meet between the third and fourth day. Thereafter the anatomic capacity continues to increase at about the previous absolute rate. The physiologic capacity, however, rises much more slowly and is soon established slightly above that of the anatomic capacity. Evidently the constant relation which exists between the average physiologic and the average gastric capacity during the greater part of the suckling period is established during the middle part of the first week.

Taken as a whole, the figures on physiologic capacity which are presented here are distinctly higher than those of the earlier investigators mentioned at the beginning of this paper. This is not surprising considering that most of these workers made their observations upon infants which were fed eight or more times a day. The differences between our results and those of other recent observers are not very great.

The most noticeable feature of this series of observations is the marked change in physiologic capacity which takes place on the fourth or fifth day. This change is seen in all of the values of physiologic capacity which we have determined—in the absolute physiologic capacity both average and average maximum, in relative capacity, in percentage increments of both the average and the average maximum capacity, and in the two simple measures of variability which we have employed. In the first four days all measures of gastric capacity show a very rapid increase while in the last six days of the period of observation the increment is comparatively slow. In the first four days, also, the degree of variability in physiologic capacity is changing rapidly while in the latter part of the period it stands at a fairly constant figure.

The rapid gain in physiologic capacity of the first four days is probably no index of the actual growth of the stomach of this period

since it is almost the end of this time before the physiologic capacity of the stomach equals the anatomic capacity. The figures and curves relating to this part of the period of observation are criteria of the ability of the mother to furnish food and of the ability of the infant to ingest it rather than actual measures of the growth of the stomach in cubic capacity. Similarly, the indices of variability which have been presented are measures of the variability of the above factors rather than of gastric capacity proper.

The later gain in physiologic capacity, from the fourth to the eleventh day, probably approaches much closer to the real index of the stomach's growth since it is substantially the same as the increase in anatomic capacity.

Unfortunately, we have no available data on the weight or surface area of the stomach in the first few days after birth to enable us to determine whether the growth of the organ in these respects is comparable with the changes in capacity. It is known, however, that the growth of the stomach in net weight is very great in the first post-natal months when the organ is increasing most rapidly in capacity.

As has been pointed out, our figures indicate that the absolute physiologic capacity increases, though not directly, with the birth weight of the child. This finding agrees with the earlier observations of Ssnitkin⁵ on physiologic capacity. On the other hand, Holt²⁰ in his study of anatomic capacity, found no relation between this measure and body weight. However, his observations were made mainly on older children. That the relative physiologic capacity of groups of lighter children is greater than that of heavier groups has not, we think, been specifically pointed out previously, although several recent studies, such as those of Reicke²⁴ and Hammett,²⁵ have noted a relatively rapid rate of growth of premature infants which might be expected to be associated with a greater relative food intake. There are few published figures on the relative gastric capacity in the neonatal period. The only ones based on an extensive series of cases are those of Ssnitkin,⁵ who calculated that the average meal was equal to 1 per cent. of the body weight plus 1 gm. for each day of postnatal life. This rule gives values far below those quoted in our tables despite the fact that our percentages are figured on the birth weight rather than the actual weight at the time of feeding. This discrepancy is probably due in part to the feeding methods employed in Ssnitkin's cases, and in part to the fact that his observations extended over the entire first month while ours were limited to the first ten days of post-natal life.

24. Reicke, A.: Das Wachstum der Frühgeburten in den ersten Lebensmonaten, *Ztschr. f. Kinderh.* **13**:332, 1915.

25. Hammett, F. S.: The Relation Between Growth Capacity and Weight at Birth, *Am. J. Physiol.* **45**:396, 1918.

Our figures show no constant differences in the physiologic capacity of first born and later children, except for the group of heaviest cases. This result was unexpected for a priori one might expect that first born children would take smaller meals than later ones both because of greater birth trauma, which would limit their power of nursing, and because the mammary glands of primiparae begin to function a little later after delivery than do those of multiparae. While the difference in this later factor in multiparae and primiparae is one of hours only, according to Landois' ⁹ observations, still one might expect it to affect our averages slightly. It may be that our findings in this particular are due to the nature of the material studied, for it is the practice of the University Hospital to receive all primiparae for delivery while multiparae are only received when there is record of previous difficult deliveries, when pathologic symptoms are observed, or when the social conditions of the mother are adverse. By far the larger number of multiparous mothers of our series were admitted to the hospital for delivery because of adverse social circumstances. Possibly these circumstances have influenced the physical condition of the mothers to the extent of limiting the milk supply during the first ten days postpartum.

The group of heaviest children in our series (those having a birth weight of 4,000 gm. or more) show several peculiarities of gastric capacity not seen in the groups of smaller infants. These heavier children have smaller relative anatomic capacities at birth than do the lighter ones and their physiologic capacities, both absolute and relative, are smaller in the first week of life. In the early part of the second week the absolute physiologic capacity in this group rises above that of the lighter groups of children but the relative physiologic capacity remains far below throughout the period of observation. In this group, also, parity has a distinct effect on physiologic capacity, and the averages of first born children are distinctly below those of later children. We are inclined to attribute most of these peculiarities in physiologic capacity to the greater trauma which these children undergo at birth.

SUMMARY

The results of this study may be summarized as follows:

1. The average physiologic capacity of the stomach in the first day after birth is about 7 gm. This practically doubles in the second day, quadruples on the third, and increases almost sevenfold on the fourth. After the fourth day, the increase is much slower and the average capacity on the tenth day is 81 gm. or over eleven times that of the first day. The average maximum physiologic capacity increases in much the same manner as the average physiologic capacity.

It is about one-fourth greater than the average physiologic capacity on the first day and about two-thirds greater on the second. Thereafter the difference between the two measures decreases rapidly until the sixth day. After the sixth day the average maximum capacity remains about one-third more than the average capacity.

2. The relative physiologic capacity increases in much the same way as the absolute physiologic capacity. It is equal to 0.21 per cent. of the birth weight of the body on the first day, to 1.38 per cent. on the fourth day, and 2.43 per cent. on the tenth day. The relative maximum capacity is equal to 0.27 per cent. of the initial body weight on the first day, to 1.96 per cent. on the fourth day, and to 3.17 per cent. on the tenth day.

3. In the first ten days parity has no constant effect on the physiologic capacities of children having an initial body weight of from 2,000 to 4,000 gm. Sex has no effect on the physiologic capacity in this period.

4. The average deviation in physiologic capacity rises rapidly from the first to the fourth day. Thereafter it increases very slowly. The percentage deviation decreases rapidly until the fifth day and thereafter continues to drop very slowly.

5. All indices of physiologic capacity indicate that there is a distinct change in the nature of this value about the fourth day. Until this time the increase in capacity, in whatever manner it is calculated, is very rapid, thereafter it is much slower. In the first four days average deviation in capacity is increasing rapidly and percentage deviation is decreasing rapidly. After this time both of these measures change very little.

6. The anatomic capacity of the stomach at birth averages 33 c.c. This is increased about one-third in the first three or four days and is a little more than doubled in the second week. There is no indication of two definite stages in the development of anatomic capacity in the neonatal period corresponding to the two phases of physiologic capacity. Anatomic capacity and physiologic capacity approximate one another about the fourth day. Thereafter physiologic capacity runs parallel to the anatomic capacity but is slightly greater. This agrees with previous findings regarding this relation throughout the greater part of the suckling period.

7. The curve representing average physiologic capacity in the first ten days of post natal life shows two phases. The first segment, extending from birth to the fourth day, shows little relation to the actual capacity of the organ but is rather a measure of the ability of the average mother to furnish nourishment in this period and the ability of the average child to receive it. The second segment, extend-

ing from the fourth to the tenth day, is probably a fair measure of the actual increase in gastric capacity comparable with similar measures of this value made at later times in the sucking period.

8. The gastric capacities of children weighing 4,000 gm. or over at birth are somewhat different from those of infants of lighter weights. Both the average and the average maximum physiologic capacities of this group are smaller than those of lighter children in the first three or four days of post natal life but these values increase rapidly in the fifth and sixth days and before the end of the period exceed those of smaller infants. Parity has a slight but distinct effect on physiologic capacity in this group of large infants, and first born children have a smaller capacity than do the later born. The anatomic capacities of children of this group are somewhat greater absolutely but smaller relatively than in children of the lighter groups.