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Research Article

# BREATHING MEASUREMENTS ON NORMAL NEWBORN INFANTS

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## INTRODUCTION

Observations upon the frequency and amplitude of the respiratory movements of newborn children, recorded in the literature, are conflicting. The rate of breathing per minute is recorded as follows: Dohrn (1), 62; Eckstein and Rominger (2), 37 to 49; Pfaundler and Schlossmann (3), 40 to 45; and Feldman (4), 44.

The depth of breathing, expressed in cubic centimeters, is given by Feldman (4) as 48; Dohrn (1), 45; Pfaundler and Schlossmann (3), 27 to 42; von Recklinghausen (5), 19.5; Gregor (6), 15; and Eckstein and Rominger (2), 10 to 13.

The amount of air breathed per minute is 1300 cc. according to Eckerlein (7), while Eckstein and Rominger (2) record 600 to 1000 cc. The minute volume per kilogram of body weight is 400 cc. as reported by Feldman (4), while Pfaundler and Schlossmann (3) say that it varies from 330 to 500 cc.

Observations have been made recently with the apparatus shown in Figure 1, which are the first to be recorded by this method.

## APPARATUS

The features of the apparatus which made possible the accuracy of the method were the size and construction of the Krogh spirometer and the collar arranged to render the system air-tight and the apparatus rigid. The float of the Krogh spirometer is constructed of sheet aluminum 1/5000 of an inch in thickness. Its top measures 9.5 by 7.8 cm. The writing point end of the float extends into the water a dis-

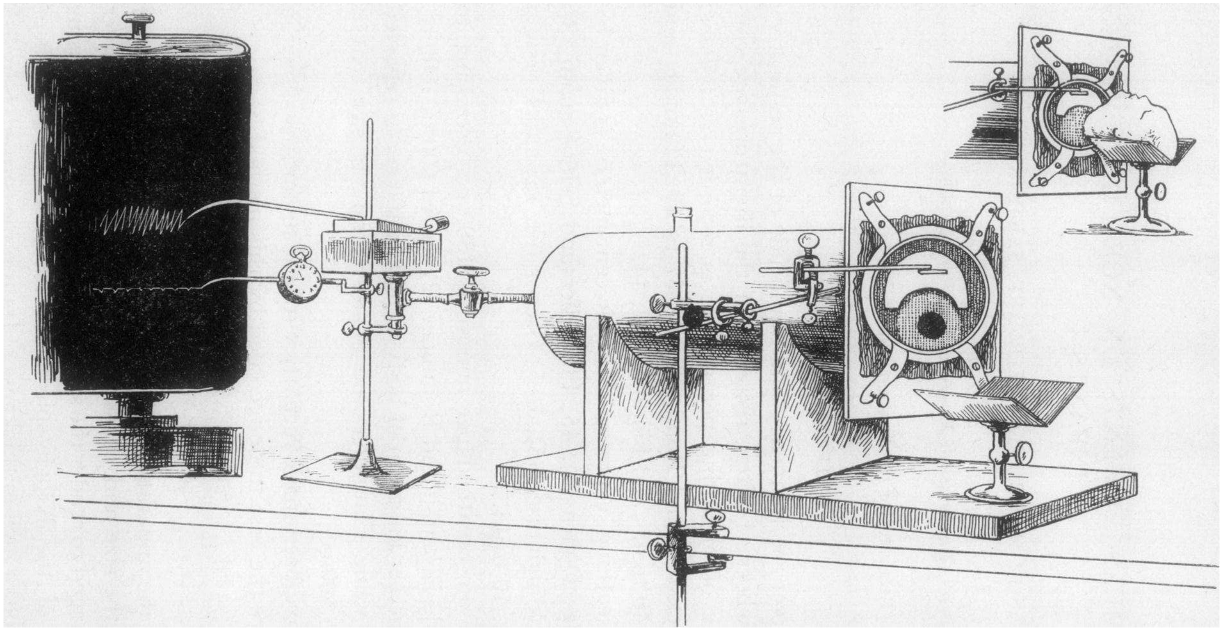

FIG. 1. APPARATUS FOR MEASUREMENT OF RATE AND DEPTH OF RESPIRATORY MOVEMENTS OF NEWBORN INFANT

Note the collar arrangement for creating an air-tight seal about the neck. The central portion of the collar is thinner than the peripheral part. The fenestration being smaller than the neck, the rubber must be stretched. This increases its rigidity, which is further augmented by pressure from the metallic crescentic-shaped shutter.

tance of 5.3 cm., the opposite end 2 cm. The rubber collar [1] is 25 cm. in diameter. The peripheral portion is 2.5 mm. thick, the central portion .5 mm. The central opening is 2.5 cm. in diameter.

Calibration of the spirometer, using a burette and a gravity-bottle for water displacement, indicated that a movement of 10 cc. of air would alter the pointer of the spirometer a distance of 7 mm. No difference in the calibration was noted when the plethysmograph was included in the system with appropriate fixation of the rubber collar, to simulate that effected when the infant was in position.

To determine the error introduced by *rapid* changes of air volume, further calibration was carried out by the use of a new Record syringe. The latter by calibration was set to transfer 21.4 cc. of air per stroke. Using very slow movement of the piston the position of the spirometer pointer moved a distance of 13.0 mm. for each 21.4 cc. of air transferred. Employing an alternating filling and emptying of the spirometer, at a rate of 54 fillings per minute, 15.2 mm. displacement of the pointer was the average produced per stroke, whereas a rate of 104 per minute increased this movement to 15.5 mm. per average stroke.

With the plethysmograph in the system, the neck opening of the collar plugged with a beaker, the crescentic shutter in place, and the lower part of the collar also made rigid by slight constant pressure against the beaker, calibration was repeated. Moving the syringe at a rate of 54 strokes per minute, the pointer moved 15 mm. on the average, while a rate of 104 gave a pointer excursion of 15.1 mm.

The observations were carried out upon infants born in the University of Pennsylvania Hospital during the months of June, July, August and September 1930. Tests were made within the first day or two of birth when possible (Table 3). The selection of infants was based upon size and the fact that careful physical examination revealed no abnormalities. Of 74 tested infants, one later exhibited signs of parathyroid tetany and three developed a mild degree of dehydration fever. Three-quarters of the entire group of 74 infants were observed by one of us in the outpatient department for the three months following the breathing tests and were normal throughout that time. The

[1] This portion of the apparatus is standard equipment for the infant-size, Drinker respirator and can be purchased through the Warren E. Collins Co. of Boston, Massachusetts.

breathing of the infant having tetany did not deviate from the average in any respect.

## PROCEDURE

To secure the quietest breathing and therefore a record of minimum ventilation, an attempt was made to measure only sleeping infants. Tests were done immediately after feeding time. If the infant was not sleepy it was given an additional feeding of 5 per cent Karo syrup in warm water. Weight and body measurements were recorded (Tables 1 and 4). A continuous tracing was made attempting to secure a record of from 10 to 20 minutes of breathing during sleep. Sleep was not always continuous, however, throughout the period. Each infant was measured only once.

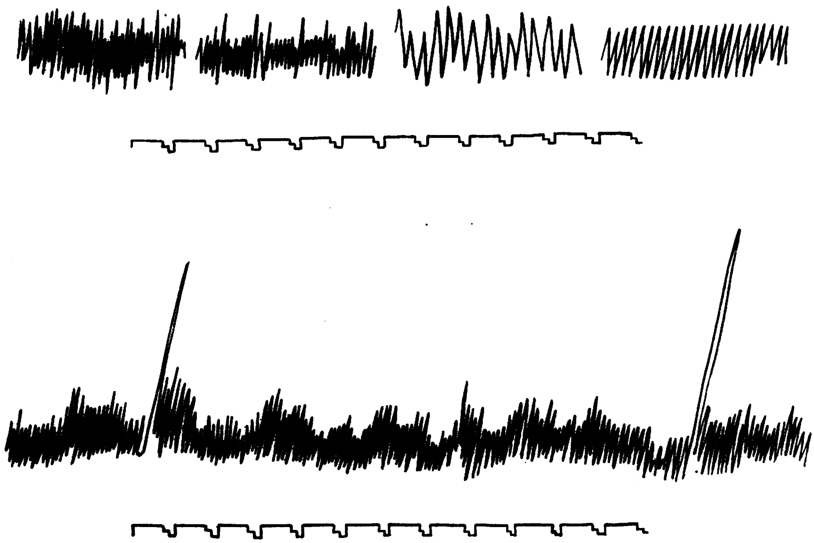

FIG. 2. PLETHYSMOGRAPHIC RECORDS MADE ON 5 SLEEPING INFANTS UNDER 48 HOURS OF AGE, SHOWING THE CHARACTERISTIC IRREGULARITIES OF THE BREATHING RHYTHM.

Note the two deep sighs in the lower tracing. Time marker records 5 second intervals.

After the tracings were shellaced and ready for examination selected parts showing the slowest and most uniform breathing from the record of each infant were chosen in the following manner: Those parts of each tracing made during sleep were subdivided into samples one-half minute in length. Avoiding the choice of consecutive samples, the three samples showing the slowest breathing rates were selected and each was measured in the following manner: Using a specially calibrated rule, each inspiratory stroke of the sample was measured with dividers, and the summation for the half minute doubled to give the

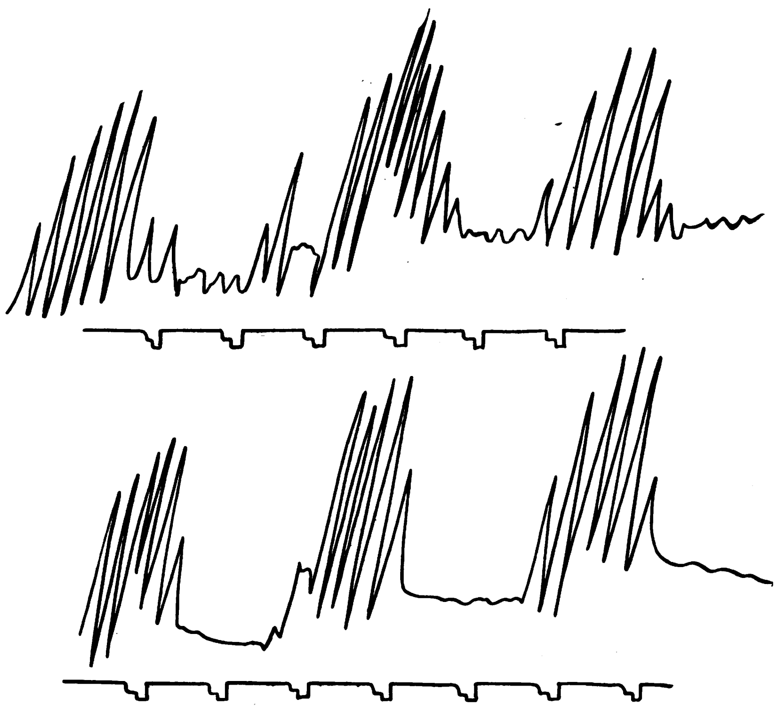

FIG. 3. SHOWING CHEYNE-STOKES TYPE OF BREATHING, ALSO IN AN INFANT UNDER 48 HOURS OF AGE

This is rarely seen, usually just at beginning of sleep, and is very transient. Time marker records 5 second intervals.

minute volume. The three minute volume figures secured in this manner were compared. If the largest was less than 10 per cent greater than the smallest, it was assumed that a suitable degree of breathing stability had been reached for the purpose of the study, and the record of this infant was placed in Table 1. Records which failed to meet this requirement are given in Table 2. Two examples of characteristic tracings are shown in Figures 2 and 3.

TABLE 1

*Data upon 50 healthy fullterm infants whose respiratory movements were studied in the apparatus shown in figure 1. Forty-seven infants were asleep, and 3 though awake gave comparable records. The body measurements were made the day of the test.*

| Serial number | Delivery* | Age | | Weight | Full length | Sitting height | Chest circumference at nipple line | Sex | Karo syrup given | Sleeping | Breathing samples: A, Respiratory rate | A, Minute volume | B, Respiratory rate | B, Minute volume | C, Respiratory rate | C, Minute volume | Average: Respiratory rate | Average: Minute volume | Average: Mean tidal air | Difference between largest and smallest minute volume |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | days | hours | grams | cm. | cm. | cm. | | | | per minute | cc. | per minute | cc. | per minute | cc. | per minute | cc. | cc. | per cent |
| 1 | A.T.F. | 2 | 1 | 3455 | 53.5 | 33.5 | 33.0 | M | – | – | 88 | 1249 | 96 | 1335 | 92 | 1222 | 92 | 1268 | 13 | 9.2 |
| 2 | O.F. | | 8 | 3740 | 50.5 | 32.5 | 35.0 | M | + | + | 60 | 880 | 62 | 920 | 58 | 902 | 60 | 902 | 15 | 4.6 |
| 3 | S. | 1 | 2 | 3957 | 50.0 | 33.0 | 35.0 | F | + | + | 116 | 1413 | 98 | 1354 | 94 | 1358 | 102 | 1375 | 13 | 4.0 |
| 4 | O.F. | | 20 | 2972 | 47.0 | 31.8 | 30.5 | F | – | + | 44 | 898 | 48 | 958 | 44 | 880 | 45 | 912 | 20 | 8.8 |
| 5 | S. | | 17 | 2508 | 47.0 | 31.0 | 28.5 | M | – | + | 38 | 566 | 38 | 557 | 38 | 574 | 38 | 565 | 14 | 3.0 |
| 6 | A.T.F. | 1 | 5 | 3778 | 50.0 | 34.5 | 34.0 | M | – | + | 52 | 870 | 58 | 898 | 56 | 814 | 55 | 860 | 15 | 10.0 |
| 7 | O.F. | | 19 | 3429 | 50.0 | 33.0 | 32.0 | M | – | + | 36 | 617 | 38 | 634 | 38 | 606 | 37 | 619 | 16 | 4.6 |
| 8 | A.T.F. | 9 | 7 | 3451 | 50.4 | 33.0 | 32.5 | F | – | + | 30 | 730 | 28 | 730 | 30 | 781 | 29 | 746 | 25 | 6.9 |
| 9 | O.F. | 9 | 0 | 3010 | 47.0 | 30.5 | 30.0 | F | + | + | 46 | 871 | 48 | 895 | 48 | 876 | 47 | 880 | 18 | 2.7 |
| 10 | O.F. | 5 | 4 | 2695 | 50.5 | 32.0 | 30.5 | F | + | + | 32 | 613 | 30 | 592 | 30 | 572 | 30 | 592 | 19 | 7.1 |
| 11 | O.F. | | 5 | 2320 | 50.5 | 32.5 | 30.5 | F | + | + | 30 | 594 | 30 | 604 | 30 | 584 | 30 | 594 | 19 | 3.0 |
| 12 | S. | | 14 | 3067 | 47.5 | 31.5 | 32.0 | M | + | + | 48 | 897 | 48 | 869 | 48 | 881 | 48 | 882 | 18 | 3.0 |
| 13 | O.F. | 2 | 1 | 2600 | 47.0 | 30.0 | 29.0 | F | + | + | 38 | 454 | 38 | 474 | 38 | 479 | 38 | 469 | 12 | 5.0 |
| 14 | B. | | 9 | 3807 | 51.0 | 33.2 | 33.5 | M | – | + | 42 | 836 | 42 | 907 | 44 | 842 | 42 | 861 | 20 | 8.0 |
| 15 | O.F. | 4 | 3 | 2972 | 49.0 | 32.8 | 33.5 | F | – | + | 40 | 635 | 36 | 662 | 38 | 672 | 38 | 656 | 17 | 5.0 |
| 16 | S. | | 5 | 3989 | 53.5 | 35.0 | 34.5 | M | – | + | 38 | 830 | 38 | 887 | 38 | 829 | 38 | 848 | 22 | 7.0 |
| 17 | O.F. | | 16 | 3473 | 49.0 | 33.2 | 32.0 | F | + | + | 48 | 967 | 46 | 923 | 46 | 1001 | 46 | 963 | 20 | 8.0 |
| 18 | O.F. | | 18 | 2816 | 49.0 | 32.0 | 26.5 | F | + | + | 42 | 581 | 46 | 591 | 44 | 564 | 44 | 579 | 13 | 4.0 |
| 19 | O.F. | 3 | 8 | 3590 | 50.0 | 34.0 | 34.0 | F | + | + | 82 | 986 | 72 | 929 | 78 | 993 | 77 | 969 | 12 | 6.0 |
| 20 | S. | | 15 | 2946 | 46.5 | 31.0 | 30.5 | F | – | + | 28 | 464 | 26 | 457 | 26 | 434 | 26 | 451 | 17 | 6.0 |
| 21 | O.F. | | 5 | 2760 | 47.0 | 31.5 | 29.5 | F | – | + | 36 | 606 | 36 | 609 | 36 | 579 | 36 | 598 | 16 | 5.0 |
| 22 | B. | | 9 | 3650 | 50.0 | 34.0 | 34.0 | M | + | + | 64 | 840 | 64 | 838 | 62 | 817 | 63 | 831 | 13 | 2.0 |
| 23 | O.F. | 4 | 16 | 3000 | 49.0 | 32.5 | 32.0 | M | – | + | 28 | 560 | 28 | 554 | 28 | 574 | 28 | 562 | 20 | 5.0 |

* *Symbols*: A.T.F. Axis-traction forceps. O.F. Outlet forceps. F. "Forceps." B. Breech delivery. S. Spontaneous delivery. + Yes. – No.

TABLE 1—*Continued*

| Serial number | Delivery* | Age | | Weight | Full length | Sitting height | Chest circumference at nipple line | Sex | Karo syrup given | Sleeping | Breathing samples A Respiratory rate | A Minute volume | B Respiratory rate | B Minute volume | C Respiratory rate | C Minute volume | Average Respiratory rate | Average Minute volume | Average Mean tidal air | Difference between largest and smallest minute volume |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | days | hours | grams | cm. | cm. | cm. | | | | per minute | cc. | per minute | cc. | per minute | cc. | per minute | cc. | cc. | per cent |
| 24 | O.F. | 10 | 17 | 2694 | 47.0 | 30.0 | 31.5 | F | + | + | 50 | 657 | 50 | 681 | 50 | 655 | 50 | 664 | 13 | 3.0 |
| 25 | O.F. | 7 | 10 | 3378 | 51.0 | 32.5 | 33.5 | F | + | + | 36 | 435 | 36 | 435 | 36 | 408 | 36 | 426 | 11 | 6.0 |
| 26 | O.F. | | 5 | 2921 | 47.5 | 30.8 | 31.5 | M | − | + | 32 | 650 | 34 | 626 | 30 | 589 | 32 | 621 | 19 | 9.0 |
| 27 | S. | | 8 | 3570 | 50.5 | 34.0 | 34.0 | F | − | + | 42 | 756 | 42 | 748 | 42 | 787 | 42 | 763 | 18 | 5.0 |
| 28 | O.F. | | 5 | 2882 | 48.0 | 32.0 | 33.0 | F | + | − | 54 | 599 | 52 | 632 | 66 | 629 | 57 | 620 | 10 | 5.0 |
| 29 | O.F. | 1 | 21 | 3155 | 48.0 | 31.2 | 32.5 | M | − | + | 38 | 588 | 38 | 574 | 38 | 544 | 38 | 568 | 14 | 8.0 |
| 30 | S. | 1 | 3 | 3370 | 50.5 | 35.0 | 33.0 | M | + | + | 46 | 678 | 46 | 698 | 46 | 637 | 46 | 671 | 14 | 9.0 |
| 31 | B. | 1 | 15 | 3690 | 51.0 | 34.2 | 34.0 | F | + | + | 60 | 649 | 58 | 692 | 62 | 636 | 58 | 659 | 11 | 8.0 |
| 32 | A.T.F. | | 5 | 3590 | 53.5 | 35.2 | 34.5 | M | − | + | 66 | 973 | 66 | 943 | 62 | 916 | 64 | 944 | 14 | 6.0 |
| 33 | O.F. | | 15 | 3112 | 49.0 | 31.2 | 32.5 | F | + | + | 44 | 577 | 44 | 575 | 46 | 561 | 44 | 571 | 12 | 2.0 |
| 34 | S. | | 7 | 3570 | 50.0 | 32.5 | 32.0 | F | − | + | 34 | 590 | 34 | 584 | 34 | 633 | 34 | 602 | 17 | 8.0 |
| 35 | S. | | 9 | 3525 | 50.0 | 33.0 | 34.0 | F | − | + | 42 | 660 | 38 | 636 | 34 | 599 | 38 | 631 | 16 | 10.0 |
| 36 | S. | 2 | 17 | 2647 | 49.0 | 30.8 | 30.5 | F | − | + | 24 | 489 | 24 | 481 | 26 | 506 | 24 | 492 | 20 | 5.0 |
| 37 | S. | 1 | 22 | 3131 | 50.0 | 32.5 | 32.0 | M | + | − | 38 | 670 | 40 | 669 | 42 | 699 | 40 | 679 | 12 | 4.0 |
| 38 | F. | 2 | 22 | 3102 | 51.0 | 33.6 | 33.5 | F | − | + | 28 | 492 | 28 | 516 | 26 | 503 | 27 | 503 | 18 | 4.0 |
| 39 | O.F. | 1 | 3 | 2441 | 47.5 | 31.0 | 27.5 | F | − | + | 34 | 649 | 32 | 624 | 34 | 603 | 33 | 625 | 18 | 7.0 |
| 40 | O.F. | 1 | 8 | 3100 | 51.0 | 33.5 | 31.0 | M | − | + | 60 | 947 | 60 | 938 | 60 | 947 | 60 | 944 | 15 | 0.0+ |
| 41 | A.T.F. | 1 | 22 | 3070 | 50.0 | 31.5 | 31.5 | F | + | + | 32 | 660 | 32 | 643 | 32 | 643 | 32 | 628 | 19 | 0.2 |
| 42 | S. | | 9 | 3005 | 48.0 | 31.5 | 32.0 | M | − | + | 28 | 728 | 26 | 741 | 26 | 711 | 26 | 726 | 27 | 0.4 |
| 43 | S. | | 11 | 3460 | 49.0 | 32.5 | 33.5 | M | − | + | 30 | 753 | 32 | 758 | 32 | 722 | 31 | 744 | 24 | 4.0 |
| 44 | O.F. | 2 | 2 | 3235 | 51.5 | 33.0 | 32.0 | M | − | + | 44 | 746 | 44 | 760 | 40 | 712 | 42 | 739 | 17 | 6.0 |
| 45 | S. | | 4 | 3485 | 49.5 | 33.0 | 33.0 | F | − | + | 40 | 596 | 42 | 647 | 40 | 627 | 40 | 623 | 15 | 8.0 |
| 46 | O.F. | | 9 | 2970 | 47.5 | 31.0 | 31.0 | M | − | + | 26 | 496 | 26 | 513 | 26 | 534 | 26 | 514 | 19 | 7.0 |
| 47 | B. | 1 | 0 | 3057 | 50.5 | 32.5 | 32.0 | F | + | + | 34 | 717 | 34 | 659 | 34 | 708 | 34 | 694 | 20 | 8.0 |
| 48 | S. | | 22 | 3445 | 51.5 | 33.0 | 31.5 | F | − | + | 28 | 723 | 28 | 676 | 26 | 702 | 27 | 700 | 25 | 6.0 |
| 49 | F. | 1 | 0 | 3922 | 51.0 | 33.0 | 34.5 | M | − | + | 56 | 828 | 56 | 832 | 58 | 874 | 56 | 844 | 15 | 5.0 |
| 50 | S. | 1 | 1 | 3605 | 51.0 | 33.5 | 33.0 | F | − | + | 52 | 861 | 52 | 857 | 52 | 858 | 52 | 858 | 16 | 0.0+ |

TABLE 2

*Observations upon 24 healthy fullterm infants which deal with plethysmographic measurements of the frequency and amplitude of the respiratory movements. These infants were not asleep when tested, and their stability of breathing was less than that of the infants recorded in table 1.*

| Serial number | Delivery* | Age | | Weight | Full length | Sitting height | Chest circumference at nipple line | Sex | Karo syrup given | Sleeping | Breathing samples A | | Breathing samples B | | Breathing samples C | | Average | | | Difference between largest and smallest minute volume |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | Respiratory rate | Minute volume | Respiratory rate | Minute volume | Respiratory rate | Minute volume | Respiratory rate | Minute volume | Mean tidal air | |
| | | days | hours | grams | cm. | cm. | cm. | | | | per minute | cc. | per minute | cc. | per minute | cc. | per minute | cc. | cc. | per cent |
| 51 | O.F. | 5 | 3 | 3310 | 52.0 | 34.0 | 32.5 | F | − | + | 52 | 627 | 42 | 579 | 50 | 720 | 48 | 642 | 13 | 24.3 |
| 52 | B. | 1 | 0 | 3154 | 50.5 | 33.0 | 32.0 | M | − | − | 56 | 995 | 60 | 668 | 70 | 1135 | 62 | 932 | 15 | 70.0 |
| 53 | S. | 1 | 1 | 3503 | 50.0 | 32.8 | 32.9 | M | − | + | 68 | 1017 | 52 | 774 | 56 | 862 | 58 | 884 | 15 | 31.4 |
| 54 | S. | | 17 | 6920 | 49.0 | 32.0 | 32.0 | M | + | − | 74 | 917 | 76 | 986 | 70 | 824 | 73 | 909 | 12 | 19.6 |
| 55 | O.F. | | 8 | 3580 | 51.0 | 31.0 | 34.5 | F | − | + | 56 | 1111 | 42 | 776 | 40 | 708 | 46 | 865 | 18 | 57.0 |
| 56 | A.T.F. | 5 | 0 | 3516 | 49.0 | 30.6 | 30.2 | M | + | + | 72 | 805 | 70 | 778 | 90 | 1422 | 77 | 1001 | 13 | 82.6 |
| 57 | O.F. | 1 | 9 | 2764 | 49.0 | 32.3 | 31.4 | F | − | + | 46 | 820 | 56 | 1093 | 46 | 940 | 49 | 951 | 19 | 33.3 |
| 58 | O.F. | | 12 | 4631 | 54.0 | 36.0 | 37.5 | F | − | + | 94 | 1503 | 96 | 1564 | 74 | 1215 | 88 | 1427 | 16 | 28.7 |
| 59 | A.T.F. | 23 | 10 | 3304 | 52.0 | 34.0 | 32.2 | M | − | − | 70 | 1327 | 58 | 1188 | 68 | 1232 | 65 | 1249 | 19 | 11.7 |
| 60 | O.F. | 10 | 12 | 3246 | 52.0 | 35.0 | 33.0 | M | − | + | 54 | 842 | 48 | 825 | 40 | 716 | 47 | 794 | 17 | 17.6 |
| 61 | S. | 6 | 18 | 2760 | 48.0 | 31.0 | 31.0 | M | + | + | 36 | 696 | 38 | 666 | 38 | 620 | 37 | 660 | 17 | 12.2 |
| 62 | O.F. | | 16 | 3400 | 49.0 | 33.0 | 32.5 | M | + | − | 44 | 709 | 42 | 674 | 52 | 782 | 46 | 721 | 15 | 16.0 |
| 63 | A.T.F. | | 7 | 3315 | 49.5 | 31.8 | 32.5 | F | − | + | 30 | 720 | 38 | 799 | 28 | 602 | 32 | 707 | 22 | 32.7 |
| 64 | O.F. | 2 | 9 | 3129 | 48.5 | 33.5 | 32.5 | M | + | + | 68 | 764 | 62 | 769 | 48 | 674 | 59 | 735 | 12 | 14.1 |
| 65 | S. | 1 | 4 | 2629 | 47.0 | 30.5 | 30.0 | F | + | − | 42 | 945 | 40 | 661 | 44 | 810 | 42 | 805 | 19 | 43.0 |
| 66 | B. | 1 | 9 | 3286 | 49.0 | 31.0 | 30.5 | F | − | + | 72 | 936 | 76 | 1056 | 58 | 886 | 68 | 959 | 14 | 19.2 |
| 67 | F. | | 22 | 3205 | 47.5 | 31.0 | 31.7 | F | − | + | 60 | 832 | 62 | 881 | 56 | 780 | 59 | 831 | 14 | 12.9 |
| 68 | O.F. | 2 | 19 | 3444 | 51.0 | 32.5 | 33.5 | M | − | + | 74 | 1002 | 76 | 1012 | 62 | 884 | 70 | 966 | 13 | 14.5 |
| 69 | S. | 1 | 8 | 2418 | 44.0 | 29.5 | 30.0 | F | − | + | 60 | 643 | 44 | 497 | 52 | 519 | 52 | 556 | 10 | 29.4 |
| 70 | S. | 5 | 9 | 2285 | 48.5 | 30.0 | 29.8 | M | + | + | 80 | 914 | 82 | 871 | 68 | 693 | 76 | 826 | 10 | 46.0 |
| 71 | S. | 10 | 15 | 3260 | 50.0 | 33.0 | 33.5 | M | + | + | 78 | 1139 | 58 | 896 | 68 | 917 | 68 | 984 | 14 | 28.0 |
| 72 | S. | | 19 | 2947 | 51.0 | 33.0 | 31.5 | F | + | + | 36 | 903 | 40 | 844 | 36 | 704 | 37 | 817 | 22 | 26.0 |
| 73 | B. | 3 | 7 | 2371 | 46.0 | 30.0 | 29.4 | F | − | − | 80 | 914 | 82 | 871 | 68 | 693 | 76 | 826 | 10 | 24.0 |
| 74 | O.F. | | 4 | 3501 | 50.0 | 33.5 | 32.0 | F | − | + | 40 | 645 | 36 | 654 | 40 | 728 | 38 | 675 | 17 | 12.0 |

* *Symbols:* A.T.F. Axis-traction forceps. O.F. Outlet forceps. S. Spontaneous delivery. B. Breech delivery. F. "Forceps." + Yes. − No.

## RESULTS

Of the 74 infants described in Tables 1 and 2, records were obtained from 47 during sleep, and also from 3 others, not sleeping, satisfactorily uniform records were secured. The results for these 50 infants are given in Table 1. The results for the remaining 24 infants are given in Table 2. The summaries found in the other tables and graphs and our conclusions are based upon the material in Table 1. The material in Table 2 is included for the sake of completeness and to show the difficulty of securing records of sleeping breathing and to indicate the great variability in the respiratory movements in the newborn child. A summary of the data dealing with the ages of the 50 subjects described in Table 1 is recorded in Table 3. The majority were tested during the first 48 hours of life.

TABLE 3

*Summary of data from table 1, to indicate the age of the [majority of] infants when tested*

| Age at test | Number of infants |
|---|---|
| During 1st 24 hours | 27 |
| During 2nd 24 hours | 10 |
| During 3rd 24 hours | 5 |
| 4th to 11th days inclusive | 8 |

TABLE 4

*Brief summaries of data taken from table 1*

| | Weight | Length | Sitting height | Chest circumference at nipple line | Respiratory rate | Minute volume | Mean tidal air |
|---|---|---|---|---|---|---|---|
| | *grams* | *cm.* | *cm.* | *cm.* | *per minute* | *cc.* | *cc.* |
| Maximum | 3989.0 | 53.5 | 35.2 | 35.0 | 116.0 | 1413.0 | 27.0 |
| Minimum | 2320.0 | 46.5 | 30.0 | 26.5 | 24.0 | 433.0 | 10.0 |
| Average | 3202.0 | 49.5 | 32.5 | 32.1 | 43.1 | 721.4 | 16.7 |

The maximum, minimum, and average figures for breathing rate, depth and minute volume are recorded in Table 4. The figures for rate and minute volume in this table are based upon the three samples (A, B, and C, Table 1) for each of the 50 infants. The mean tidal air is computed from the average rate and minute volume of the three samples from each infant. Both are based on 150 samples with the group average computed differently. These observations indicate the wide variation which may be expected in the breathing rate and amount of ventilation in sleeping newborn infants, and also the variation in mean tidal air.

A frequency distribution of the breathing rate is found in Figure 4.

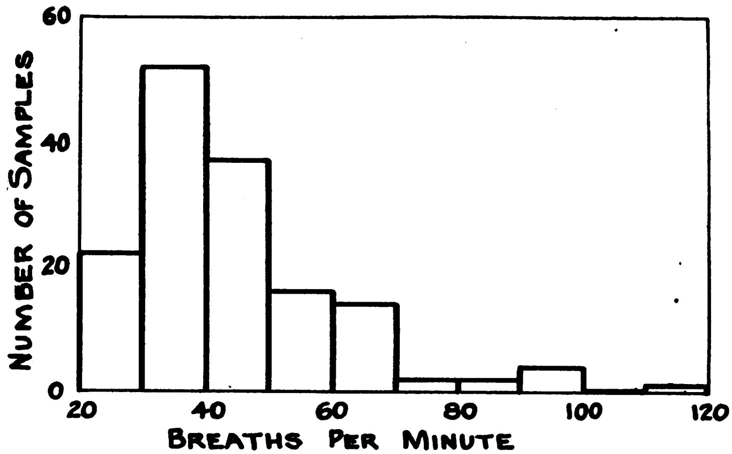


FIG. 4. DISTRIBUTION CURVE OF BREATHING FREQUENCY OF THE 50 INFANTS DESCRIBED IN TABLE 1

The abscissae indicate the number of breaths per minute. The ordinates record the number of breathing samples (3 for each infant). Note that the largest number of samples were registered by infants which breathed between 30 and 40 times per minute.

It is based on the 150 samples of the 50 infants described in Table 1. It will be evident that the largest group of infants breathed less than 40 per minute, though the average rate was 43.1 (Table 4). However there was a marked decrease in numbers of infants whose rate exceeded 50 per minute.

Figure 5 records the frequency distribution of the minute volume of air in the 50 sleeping infants. The largest group of infants breathed between 600 and 700 cc. per minute while extremely few breathed more than 1000 cc. These observations, like the ones in Figure 4, are based upon the 150 samples from the 50 infants.

Figure 6 is a graphic record of the depth of the breathing, based on the mean tidal air for each infant (Table 1). From this chart it is

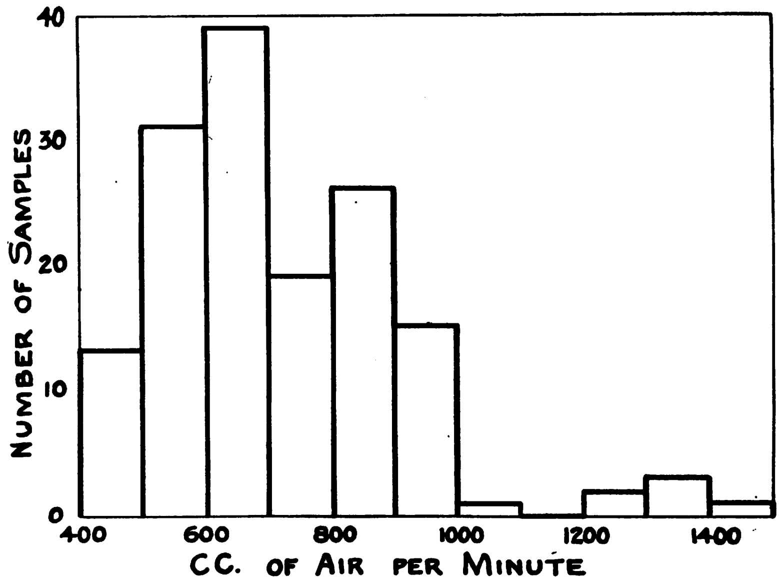


FIG. 5. DISTRIBUTION CURVE OF MINUTE VOLUME OF THE INFANTS DESCRIBED IN TABLE 1

The abscissae indicate the amount of air breathed per minute, arranged in units of 100 cc.; the ordinates the number of samples (3 for each of 50 infants). Note that the majority of infants breathed less than 1000 cc. per minute, and that the largest single group less than 700 cc.

evident that the greater number of the 50 infants breathed between 12 and 20 cc. per breath.

Two infants were tested twice daily (Table 5). Their records indi-

TABLE 5

*Breathing data on 2 infants tested twice the same day, both times asleep. Note the rate and minute volume variations in the case of infant A, while the breathing depth remained constant. Figures represent averages of 3 samples.*

| | Respiratory rate | Mean tidal air | Minute volume |
|---|---|---|---|
| | *per minute* | *cc.* | *cc.* |
| Infant A, a.m. | 42 | 11 | 487 |
| p.m. | 64 | 11 | 704 |
| Infant B, a.m. | 44 | 14 | 642 |
| p.m. | 38 | 16 | 631 |

cate the variability in rate and minute volume which may be expected at different times within the same day, though the infants were sleeping and were presumably under identical conditions at both periods.

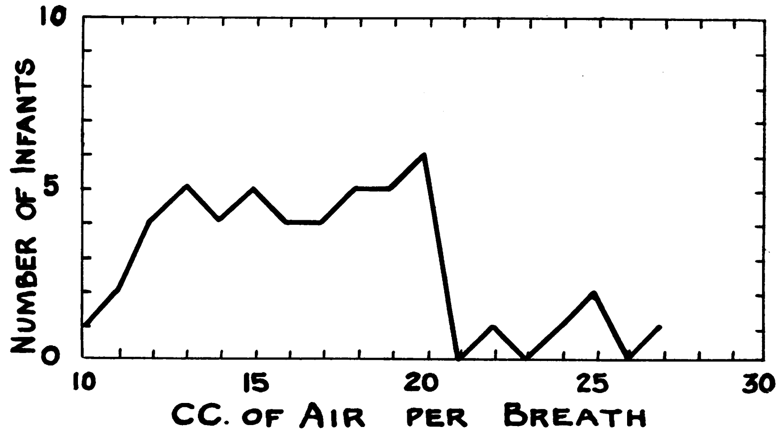


FIG. 6. DISTRIBUTION CURVE OF BREATHING DEPTH OF THE 50 INFANTS DESCRIBED IN TABLE 1

The abscissae indicate the size of the average breath (calculated from the average minute volume and the average rate, Table 1); the ordinates indicate the number of infants. Note that the great majority of the infants breathed between 12 and 20 cc., and that the numbers were fairly evenly distributed within these limits.

TABLE 6

*Breathing measurements of 4 sleeping infants taken on 3 successive days. Note wide variations in rates and in minute volumes. Figures represent averages of 3 samples*

| | Respiratory rate | Mean tidal air | Minute volume |
|---|---|---|---|
| | *per minute* | *cc.* | *cc.* |
| Infant A, 1st day | 38 | 14 | 568 |
| 2nd day | 60 | 13 | 783 |
| 3rd day | 54 | 13 | 708 |
| Infant B, 1st day | 46 | 14 | 671 |
| 2nd day | 47 | 13 | 638 |
| 3rd day | 32 | 17 | 545 |
| Infant C, 1st day | 64 | 14 | 944 |
| 2nd day | 36 | 17 | 639 |
| 3rd day | 42 | 16 | 707 |
| Infant D, 1st day | 44 | 12 | 571 |
| 2nd day | 44 | 11 | 511 |
| 3rd day | 32 | 14 | 471 |

Four infants were tested on each of three successive days (Table 6). These records like the preceding ones (Table 5) indicate wide variation in breathing activity and show the change that can be expected in the same infant from day to day. Both sets of observations show clearly that the ventilation is increased chiefly by an increase in rate, rather than by an increase in the depth of breathing. These infants (Tables 5 and 6) were measured under conditions similar to those maintained for the subjects of Table 1.

## COMMENT

The observations recorded in Tables 1 and 2 are presented simply as a set of physiological measurements. An attempt to correlate the variations of the respiratory movements with other factors failed to yield deductions of any value. The study, however, indicates that the plethysmographic measurement of the breathing of the newborn is a practical and accurate method.

Even when sleeping, the breathing of the newborn infants appears to vary within rather wide limits. This is observed chiefly in changes of rate, while the depth of the breathing remains relatively uniform. Thus breathing varies for reasons that as yet are not understood. In view of this marked variation, which is to be found in the same infant at different periods of the day, as well as on successive days, it is evident that in estimating the infant's physical condition its breathing rate should not be unduly stressed and this normal variation in breathing rate should be taken into consideration.

It has been stated that there is a gradual expansion of the lung in the newborn infant from day to day during the period immediately after birth. The present observations confirm this statement as will be seen by a glance at Table 6. It will be noted that the mean tidal air in infants B, C, and D increased with age. Our observations indicate that the degree of lung expansion cannot be estimated satisfactorily if only a few measurements of the rate of breathing and minute volume are taken into consideration, since these vary so widely from day to day.

The breathing rate as observed by us agrees fairly closely with rates noted by previous authors. The mean tidal air of the sleeping infant, however, appears to be less than that recorded by other observers. Also the minute volume measurements recorded by us are lower. The minute volume per kilogram of body weight as reported by Feldman and by Pfaundler and Schlossmann is between 330 and 500 cc., while the average for the present series of observations is only 220 cc.

It should be stated here that the present measurements are the only ones yet made upon a series of sleeping infants. For that reason they cannot be compared statistically with those of observers who measured wakeful infants.

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