TOTAL BODY WATER CHANGES DURING HIGH VOLUME PERIPHERAL HYPERALIMENTATION

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THE MAINTENANCE of normal growth in surgical and depleted pediatric patients with total hyperalimentation is rapidly becoming an accepted mode of therapy. Several investigators have demonstrated weight gain and positive nitrogen balance in patients supported solely by intravenously administered nutrition. Whether the weight gain observed is due to an increase in lean body mass or simply due to water retention secondary to the large volume of fluids infused is a question that has gone unanswered. Brans and associates (3) theorized that such weight gain is secondary to water retention, whereas Pildes and colleagues (18) and Driscoll and co-workers (5) attributed the weight gain to a true increase in body tissue. In studies on adults, Schoemaker and collaborators (21) and Elwyn and co-authors (8) found a slight increase in total body water postoperatively in patients maintained with intravenously administered nutrition. In a significant follow-up study, Brans and associates (2) supported earlier theories of water retention through measurements of extracellular water calculated from the corrected bromide space. They showed an association between parenteral hyperalimentation, increased weight gains and increased extracellular water in a group of six low birthweight infants compared with a control group of four orally alimented infants. They concluded that the weight gain in intravenously fed patients is due to water retention, although they admit that the increase in extracellular water seen may simply be a reflection of decreased intracellular water secondary to the intravascular infusion of a hypertonic fluid. No studies of total body water measurements of infants have been carried out to determine the basis of weight gain during hyperalimentation.

Technical difficulties and ethical considerations have precluded the use of radioactive isotopes to study this problem in infants and children. The availability of the nonradioactive substance deuterium oxide, which has absolutely no toxicity or side-effects, has made it feasible to measure total body water in infants. This study is an analysis of total body water changes in a neonatal surgical patient who was maintained with long term peripheral hyperalimentation. The analysis, as such, provides initial confirmation of the actual fluid balances involved in this mode of therapy.

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MATERIALS AND METHODS

Total body water studies were obtained on one patient, during a period of 17 weeks, who was receiving total peripheral hyperalimentation on the Pediatric Surgical Service. Permission to conduct the studies was obtained from the Human Use Committee as well as through informed consent by the parents.

The patient studied was a premature male infant, 35 weeks' gestation, who was born with gastroschisis. He underwent a primary repair plus a gastrostomy on the first day of life but later was found to have an ileal atresia as well, which was repaired with a primary anastomosis at age four and one-half weeks. At seven and 18 weeks of age, additional resections of the small intestine were required for intestinal hypotonicity together with an ileostomy. During the first 19 weeks of life, he was maintained primarily with peripheral hyperalimentation with brief unsuccessful attempts at oral feedings. From 20 to 32 weeks of age, repeated efforts at oral alimentation failed because of the presence of the short gut syndrome. The ileal stoma was closed at 32 weeks of age in a final attempt to wean the patient away from peripheral hyperalimentation and to total oral intake. The patient finally died at age 42 weeks after being unable to assimilate adequately oral alimentation.

The child was sustained with a regimen of high volume peripheral hyperalimentation that consisted of approximately 100 to 120 milliliters per kilogram per day of 2 per cent Amigen, protein hydrolysate; 12 per cent glucose solution,

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and 40 milliliters per kilogram per day of a 10 per cent fat emulsion, Intralipid. Daily caloric intake of this regimen averaged 100 to 111 kilocalories per kilogram per day. For the first eight weeks, this was essentially the only mode of alimentation. During weeks 9 and 10 as well as 12 through 16, oral supplementation with formulas was attempted but was unsuccessful. During the 17 week study period, measurements were made daily of weights and fluid intake, recording the exact amounts of intravenously administered hyperalimentation and orally administered fluids. Daily caloric intake was calculated from the known fluid intake. In addition, several crown to heel length measurements were made during the study.

Measurements of total body water were carried out at approximately three week intervals using a method of deuterium oxide dilution, previously described by Schloerb and collaborators (19, 20). Using a solution of 99.7 per cent pure deuterium oxide, a precisely measured amount of approximately 1.5 milliliters per kilogram of body weight was injected intravenously. A blood sample of at least 1.5 milliliters was obtained at approximately two and one-half hours after injection and was centrifuged; the serum was frozen and stored for analysis. When consecutive studies were undertaken, a sample of control blood was drawn from the patient immediately prior to the deuterium oxide injection, thereby measuring the residual amount of heavy water present from the previous study.

The serum samples were double distilled in a manifold glass vacuum system, using liquid nitrogen in the immersion traps to collect the condensates. In addition, a standard series of 13 samples of known deuterium oxide concentrations was double distilled in the same manner. By using a constant temperature water bath, originally developed by Schloerb and colleagues (19, 20) that allows temperature control to within 0.001 degree C., precisely measured drops of standard distillates plus study serum distillates were allowed to fall through a column of orthofluorotoluene, measuring the time required to pass between two specified points on the column. The size of the falling drop was controlled by an ultraprecision micrometer attached to a plunger and micropipette and represents an improvement in technique by Barton (1) over the original method described by Schloerb and associates (19). Twelve drops of each sample were measured. The high and low values were discarded, and the mean of the remaining ten values was used as the falling time for each sample. The variance of the range was consistently below 3 per cent of the mean. The deuterium oxide concentration of each sample is proportional to the reciprocol of the falling time. By interpolation from the falling times of the standard samples, the concentration of the study serum samples was calculated by following this formula (19):

TABLE I.—TOTAL BODY WATER CHANGES DURING PERIPHERAL HYPERALIMENTATION

Age, wks.	*Weight, kgm.*	*Total body water, L.*	*Total body water, per cent weight*
3	1.88	1.450	77.13
4	2.24	1.537	68.62
7	2.60	1.699	65.35
11	2.62	1.591	60.73
14	2.70	1.739	64.41
17	2.80	1.694	60.50

$$x=\frac{\frac{1}{E_x}-\frac{1}{t_s}}{\frac{1}{t_s'}-\frac{1}{t_s}}(s'-s)+s$$

where x equals deuterium oxide concentration of study serum in volume per cent; E_x equals falling time of study serum distillate in seconds; t_s equals falling time of lower standard distillate in seconds; t_s' equals falling time of higher standard distillate in seconds; s equals deuterium oxide concentration of lower standard in volume per cent, and s′ equals deuterium oxide concentration of higher standard in volume per cent.

After determining the deuterium oxide concentration in the study serums, the total body water was calculated by this formula:

$$v=\frac{c_1v_1-c_uv_u}{c_2}$$

where v equals total body water in liters, volume of water into whch injected deuterium oxide diffuses at equilibrium; c_1 equals concentration of injected deuterium oxide, 0.997; v_1 equals volume of deuterium oxide injected corrected at 37 degrees C. temperature, grams of deuterium oxide solution injected divided by its density at 37 degrees C. equals 1.10098 grams per milliliter; c_uv_u equals total amount of excreted deuterium oxide from time of injection to time of sampling—two and one-half hours—which represents insensible water loss plus urine loss and has been suggested by Schloerb and co-workers (7) to equal 0.4 per cent of injected deuterium oxide, c_1v_1, and c_2 equals study serum concentration of deuterium oxide at equilibrium—x from previous formula divided by 100.

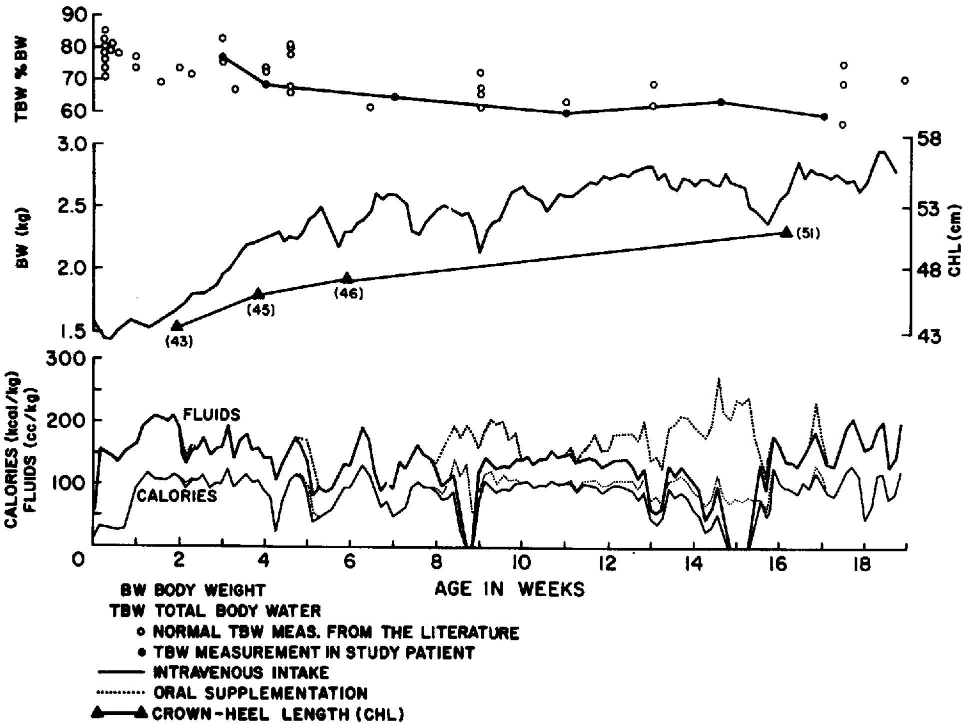

FIG. 1. Total body water changes during peripheral hyperalimentation.

RESULTS

The data of the total body water study are presented in Table I and Figure 1. In Table I is shown the gradual decrease in the total body water per cent weight from a high of 77.13 per cent at three weeks of age to a low of 60.50 per cent at 17 weeks of age. The increase in total body water per cent weight at 14 weeks may have been secondary to increased oral intake at the time of the measurement. In Figure 1, a daily summary is depicted of weight in kilograms, intravenous plus oral intake of fluids, intravenous plus oral intake of calories and the six measurements of total body water per cent weight plotted alongside the known control values of total body water per cent weight obtained from the studies of Friis-Hansen (10–13), Flexner (9), Katcher (15) and Edelman (7) and co-authors and of Osler (17).

The patient's weight increase for a period of 17 weeks averaged approximately 14 grams per day, although several shorter growth periods showed increases of as much as 35 grams per day, for example, weeks 2 to 5. In the first seven weeks, the infant gained approximately 20.4 grams per day in weight. In general, the child was unable to maintain a good rate of weight gain when given oral supplementation, thereby accounting for the decreased rate of weight gain in the latter part of the study period.

Crown to heel length increased at a fairly constant rate during the study period, the child growing at approximately 6 millimeters per week—6.4 millimeters per week during the seven week period from weeks 2 through 9 and then slightly slower for the remainder of the period.

The volume of infused fluid averaged 140 to 160 milliliters per kilogram per day, although occasionally, it rose to more than 180 milliliters per kilogram per day, especially when the child was being supplemented with oral feedings. The rate of fluid intake was consistently higher than the average 100 milliliters per kilogram per day recommended for his age group and, as such, represents a significant fluid load.

The patient's caloric needs were adequately met by the alimentation regimen. The baby was supplied with approximately 100 to 111 kilocalories per kilogram per day.

The total body water measurements show a continual drop in total body water per cent weight from a high of 77.13 per cent at three weeks of age to a low of 60.50 per cent at age 17 weeks. The one slightly higher value at 14 weeks was recorded on a day when oral hydration was at a maximum, with total fluid intake slightly greater than 270 milliliters per kilogram per day. The values of total body water per cent weight reflect the normal age related downward trend shown by control values from studies reported in the literature and previously alluded to in the manuscript. In addition, the values for total body water per cent weight are consistently on the lower end of the spectrum of known values, including measurements made during periods of increased growth rates, for example, at four weeks of age.

DISCUSSION

The weight increase exhibited by the patient during the first seven weeks, 20.4 grams per day, parallels roughly the tenth percentile line of intrauterine growth, as determined by Lubchenco and co-workers (16), although it follows a curve significantly lower than the tenth percentile. It also approximates the postnatal rate of weight gain shown by premature babies, as delineated by Jaworski (14) and, for the first two months, by Dweck and collaborators (6). In addition, it compares favorably with the growth rate of healthy, uncomplicated, premature babies reported by Cruise (4), who found an average increment of 29.7±5.5 grams per day during the first 13 weeks of life.

The rate of length of the child increases for the first seven weeks—6.4 millimeters per week —paralleling almost exactly the tenth percentile curve of intrauterine growth of Lubchenco and associates (16). The growth for a period of 17 weeks also parallels closely the long term growth of premature infants determined by Dweck and colleagues (6). Additionally, it approximates fairly closely the length increase of healthy premature babies reported by Cruise (4) at 8.5±0.8 millimeters per week for the first 13 weeks of life. Although the weight increase of the infant slowed with the increasing attempts at oral feedings, his length increase continued at an only slightly decreased rate. This may reflect adequate nutrition in spite of increasingly difficult problems with the assimilation of orally administered fluids, thereby leading to frequent occurrences of diarrhea associated with weight loss.

The data presented in this study clearly show for the first time that the weight gain associated with long term peripheral hyperalimentation is secondary to tissue accretion rather than water retention. Despite the lack of control study patients and the availability of only one patient to study, the coupling of the high volume long term hyperalimentation with good weight gain and normally falling total body water values speaks strongly for normal anabolism. Our results are entirely consistent with those of Brans and coauthors (2), since the extracellular space in the patient in our study may well have been increased at the expense of the intracellular space, while total body water was progressively decreasing. Several additional infants receiving peripheral nutrition intravenously are presently undergoing deuterium oxide measurements to determine if the findings in the present patient are reproducible.

SUMMARY

A premature baby with gastroschisis, ileal atresia and secondary short gut syndrome was sustained with the use of peripheral hyperalimentation consisting of 2 per cent Amigen, 12 per cent glucose and 10 per cent Intralipid at an average rate of 140 to 160 milliliters per kilogram per day or 100 to 111 kilocalories per kilogram per day. The weight of the child increased during the first four months to approximately 14 grams per day, with body length increasing by about 6 millimeters per week. Six reliable measurements of the total body water of the child during the four month period were obtained using deuterium oxide dilution followed by double vacuum distillation and falling drop analysis in a constant temperature chamber. Measurements obtained showed a gradual decrease of total body water from 77.13 per cent of body weight to 60.50 per cent during the study period, with values consistently on the lower end of the spectrum of known normal controls, even during periods of increased growth rates of as much as 35 grams per day. These data on total body water, coupled with the observed gains in body weight and length, support tissue accretion rather than fluid retention as the mechanism of weight gain in long term, high volume peripheral hyperalimentation.

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