THE MAINTENANCE NEED FOR WATER IN PARENTERAL FLUID THERAPY

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ONE OF THE MAJOR objectives of parenteral fluid therapy is provision of water to meet physiologic losses. These losses, the insensible and urinary losses, have been extensively studied and defined for infants and adults. It is established from these studies that both insensible loss of water and urinary water loss roughly parallel energy metabolism and do not parallel body mass (weight). Therefore, any values which are applicable to all ages must be derived from some function of energy metabolism.

Initially, and to a large extent even today, needs for water have been determined on the basis of weight in infants and on the basis of total amounts in adults. Although this serves well for infants and adults, the hapless individual between these two groups receives, at best, a rough estimate of his requirement for water.

Darrow and Pratt[1] have referred water needs directly to energy expenditure, computed from a set of tables[2] utilizing 100 calories as a basis of reference. This latter figure is well chosen since it is equivalent to 1 kg in the infant and ready transfer of familiar numbers is possible. However, the necessity for using a table and for making computations has probably served as a barrier to its widespread acceptance.

Crawford and his associates[3] have referred needs for water, and a variety of drug dosages as well, to a unit of surface area (S.A.) since surface area closely parallels basal energy metabolism. In this system surface area is computed from a height-weight nomogram.

Wallace[4] has recently devised a scheme for computing requirement for calories per kilogram from a simple formula relating calories per kilogram to age.

The following scheme was devised to permit an estimate of total expenditure of energy from weight alone using a relationship between weight and expenditure of energy that may be easily remembered (Fig. 1). The lower line in Figure 1 defines basal caloric expenditure at the various weight levels and the upper line defines estimated caloric expenditure for normal activity.[5] The line in between indicates the calculated expenditure of energy for hospitalized patients. It is calculated from the simple equations illustrated below the graph and is necessarily arbitrary. The course of the calculated line for infants implies that hospitalized infants are more active and more nearly approach normal expenditure than is the case with adults. Hospitalized children and adults are assumed to have an energy expenditure roughly midway between basal and normal levels. Using this system, expenditure of energy ranges from 100 to 3000 calories. Table I illustrates the weight comparable to each of these 100-calorie increments.

Since losses of water are a function of expenditure of energy, needs for water must be computed from some function of energy metabolism. In Table II requirements for water at various weights are compared using the different systems referred to previously. Close agreement of needs for water as determined by the various methods is apparent. There is one exception which merits comment. In computing needs for water per unit of surface area, the values in the 6 to 15 kg range are significantly less than the others calculated in

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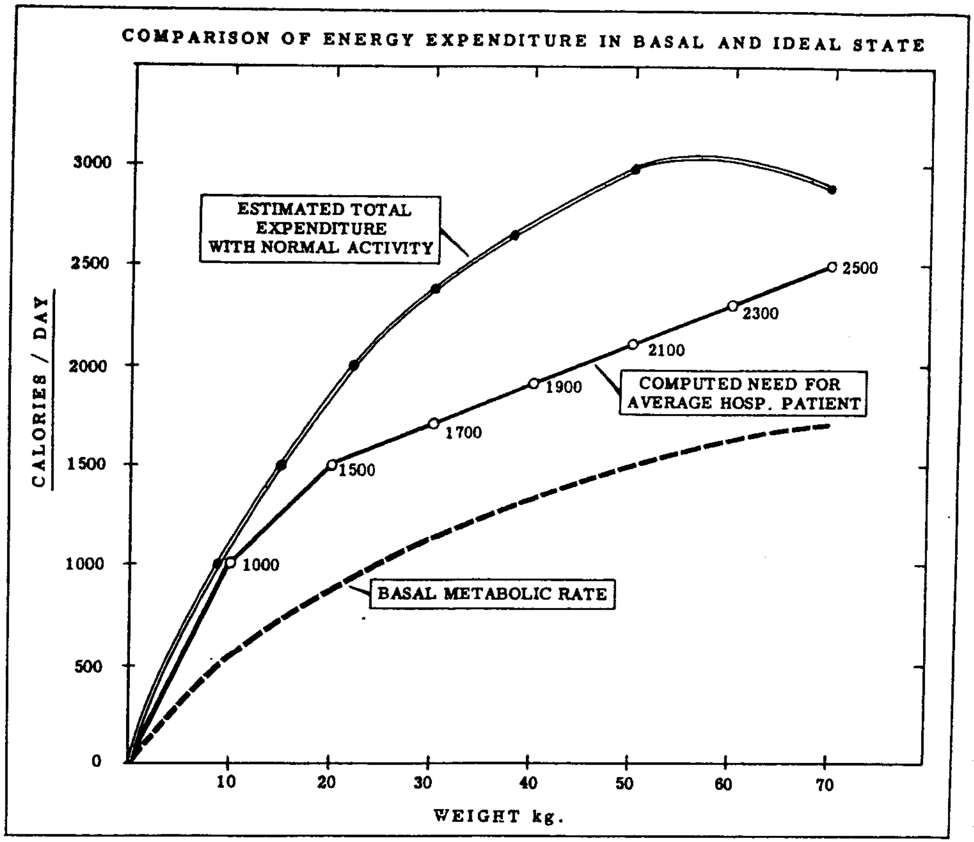


FIG. 1. The upper and lower lines were plotted from data of Talbot.[5] Weights at the 50th percentile level were selected for converting calories at various ages to calories related to weight. The computed line was derived from the following equations:

1. 0-10 kg–100 cal/kg.
2. 10-20 kg–1000 cal + 50 cal/kg for each kg over 10 kg.
3. 20 kg and up–1500 cal + 20 cal/kg for each kg over 20 kg.

that range, a finding related to the fact that energy expenditure, either basal or total, is higher per unit of surface area for the child of intermediate weight than for the small infant or for the adult. An increase of about 50% in needs for water per unit of surface area for this group would make them comparable to the other groups. With this exception, the four systems give similar results.

The higher figure in the adult range computed from the system of Darrow and Pratt results from the use of a constant percentage of basal metabolism as an estimate of activity. As noted by Darrow and Pratt, a lower percentage would more probably describe the actual activity of hospitalized adults. Accordingly, a figure comparable to the others would be obtained if this adjustment is made.

It may be appropriate to examine the two major components of loss of water, urinary and insensible, in terms of their relation to these systems.

INSENSIBLE WATER LOSS

With respect to insensible loss of water, Newburgh and Johnston[6] and Levine and Wheatley[7] have demonstrated that, for all ages, insensible loss of water in the resting state in a comfortable environment is a constant function of basal energy expenditure. The figures average 45 ml of water expended for each 100 cal of energy. At

TABLE I

Expenditure of Energy and Its Relation to Weight

Expenditure of Energy (cal)	Weight of Body (kg)	Expenditure of Energy (cal)	Weight of Body (kg)
100	1	1600	25
200	2	1700	30
300	3	1800	35
400	4	1900	40
500	5	2000	45 (average adult female)
600	6	2100	50
700	7	2200	55
800	8	2300	60
900	9	2400	65
1000	10	2500	70 (average adult male)
1100	12	2600	75
1200	14	2700	80
1300	16	2800	85
1400	18	2900	90
1500	20	3000	95

The figure of 2000 cal may be arbitrarily assigned to the average female adult. Although this correlates with a weight less than the average for adult females, it takes into account the lower metabolic rate per unit weight of females as well as the smaller weight of females in comparison to males. A suggested average for adult males is 2500 cal. Significant deviation in size could dictate appropriate deviations from this figure.

this level 25% of the total expenditure of energy is dissipated by insensible loss of water. With increased activity, adults continued to dissipate 25% of their total expenditure of heat by insensible loss of water; but with increased activity, infants showed a marked increase in insensible loss of water per 100 cal of total expenditure. The insensible loss of water rose from 45 to 90 ml/100 cal. Under these conditions 50% of the total expenditure of energy is dissipated by insensible loss of water.[7]

In hospitalized patients, insensible loss of water was estimated by Heeley and Talbot[8] to be 930 ml/m^2 for all ages compared to 750 ml/m^2 for adults in the basal state as reported by Newburgh and associates.[9] Heeley and Talbot further showed that insensible loss of water per unit of surface area was greatest in infancy and diminished with age. By recalculating these data, using the reported weights of the subjects, to express insensible loss of water in terms of estimated expenditure of energy, an average of 50 ml/100 cal/day is obtained.

Comparing the above data in terms of surface area for the various age groups to the average for the entire group, the per-

TABLE II

Needs for Water in Respect to Weight Computed from Various Systems (*ml/24 hr*)

Method of Estimation	Weight						
	3 kg	6 kg	10 kg	15 kg	20 kg	30 kg	60 kg
Cal.*	300	600	1000	1250	1500	1700	2300
S.A.† (Crawford *et al.*[3])	300	450	660	900	1200	1500	2550
Cal.** (Darrow *et al.*[1])	240	600	975	1290	1530	1950	3000
Cal.‡ (Wallace[4])	300	600	1000	1360	1640	2100	2400

* Needs for water estimated to be 100 ml/100 cal—see text.

† Needs for water estimated to be 1500 ml/m^2 for each weight computed and assuming 50th percentile height for that weight.

** Needs for water estimated to be 120 ml/100 cal as given by the author. Basal calories from the table of Talbot.[5] Activity assumed to be 30%, specific dynamic action 15%, and growth 5%. This results in a 50% increase over basal rate. (For adults a total increase of 30% is more likely.)

‡ Needs for water estimated to be 100 ml/100 cal as given by the author. Caloric need estimated as follows: cal/kg = 100 (3×age in years). Total calories then equal weight×calculated calories per kilogram.

TABLE III

Relation of Insensible Loss of Water to Surface Area and to Estimated Caloric Expenditure for Various Age Groups

Age Groups	*ml/m²*	*ml/100 cal**	*Per Cent Deviation of Each Age Group from Mean for All Ages†*	
			ml/m²	*ml/100 cal*
0– 3 yr	1150	59	124	118
3– 8 yr	950	49	102	102
8–16 yr	700	45	75	90
All ages	930	50	—	—

* Data of Heeley and Talbot[8] recalculated from weight, estimated caloric expenditure and observed insensible loss.
† Mean for all ages taken as 100% and mean for each age group expressed as per cent of this figure.

centage deviation of each of the various age groups from the over-all average may be calculated. Repeating the same calculation using the data expressed in terms of 100 cal of estimated expenditure, a similar but less marked influence of growth is demonstrated (Table III). Using surface area as the standard reference, infants have a 24% increase over the group average. Using estimated expenditure of energy as the standard reference, the increase is 18%. Similarly, values for adults by the first system are 25% below average for the group and by the second are 10% below. Therefore, 50 ml/100 cal/day represents a figure that approximates insensible loss of water for all ages. This figure agrees well with previously reported estimates.[1]

URINARY WATER LOSS

The problem of urinary water loss is best considered in terms of total excretion of solutes. The excretion of water is largely a function of the amount of solute requiring excretion and of the factors which control the concentration at which the solute is to be excreted.

These factors have been discussed in detail by Gamble,[10] Welt,[11] and Talbot.[12] Under usual conditions, solute concentrations may be varied from a low of 75 mOsm/l to a high of 1200 mOsm/l so that each milliosmol may be excreted in as much as 13.5 ml of water or as little as 0.8 ml, and the concentration is determined within these limits by the intake of water. In disease states requiring parenteral fluid therapy the limits of concentration may be considerably narrowed. In addition, the intake of water is no longer controlled by the patient in response to his own stimuli and, finally, administration of drugs as well as other stimuli may influence factors controlling excretion of water, i.e., secretion of antidiuretic hormone, independent of water intake. Accordingly, a definition of the average solute load during parenteral fluid therapy, along with some knowledge of its range, is essential in ascertaining the volume of water needed. It is furthermore desirable to consider those factors which might influence excretion of water other than intake of water and load of solutes. Such considerations would assist in ascertaining the safest concentration range and the factors which may dictate exception to the average figure for water needs.

A theoretic approach to the problem of requirements for water, in terms of excretion of solutes, during parenteral fluid therapy has been applied by Gamble *et al.*[10] and Talbot *et al.*[12] using data obtained from adults receiving glucose. In Table IV rates of excretion of solutes are illustrated for infants receiving glucose and water.[13] Two infants were shifted from a cow's milk feeding to the glucose and water feeding for a 5-day period. Later glucose and water were administered to these infants for 10 days. The data depict the average excretion of

TABLE IV

AVERAGE DAILY EXCRETION OF SOLUTES ON VARIOUS REGIMENS

Subjects	*Regimen*	*Day of Study*	*mOsm/100 cal/day*
Infants	Glucose	1	24.2
Infants	Glucose	2–5	14.5
Infants	Glucose	6–10	10.3
Adults	Glucose	Adjusted*	12.5
Infant	Human milk	Adjusted	11.0
Infant	Cow's milk	Adjusted	41.0
Adult	Average diet (1200 mOsm/day)	Adjusted	48.0

* Observation made when diet had been constant so that excretion of solutes was relatively constant.

solutes for the first day while receiving glucose and water and the average excretion of solutes during the second to fifth days. In the two experiments extended to 10 days, the daily excretion of solute for days 6 to 10 is presented and illustrates a gradual decline in excretion of solutes. Days 2 to 5 are selected as most representative of the rate of excretion of solutes during parenteral fluid therapy. Days 6 to 10 appear to represent the irreducible minimum. The figures compare well with the data of Gamble and Butler[14] in which excretion of solutes for an adult, receiving only glucose and water, was measured, when the latter was also expressed in terms of mOsm/100 cal/day. The adult was estimated to have a caloric expenditure of 2500 cal.

It is of interest to note that infants receiving human milk had a solute excretion of the same magnitude. Figures for excretion of solutes are also given for infants receiving a standard cow's milk feeding. These illustrate the greater solute excretion that results from the high protein and electrolyte intake of cow's milk. If the average diet of the adult results in the excretion of 1200 mOsm/day, the excretion of solutes expressed per 100 cal per day (48 mOsm) approximates that of the infant receiving cow's milk (41 mOsm).

The figures of greater importance in this table, however, refer to the average excretion of solutes of infants and adults receiving glucose and water. Days 2 to 5 simulate the circumstances of parenteral fluid therapy with respect to energy metabolism. The average figure for this period is 15 mOsm/100 cal/day. Normally, in parenteral fluid therapy, extra electrolyte is included which will provide an excess of from 3 to 7 mEq of cation per 100 cal per day. This leads to an addition of 6 to 14 mOsm/100 cal/day to the total excretion of solutes. Using the mean of these figures, 10 mOsm/100 cal/day, the total daily excretion of solutes then averages 25 mOsm/100 cal (15 mOsm/100 cal from energy metabolism + 10 mOsm/100 cal extra electrolyte). From Table IV the minimal excretion of solutes that would be encountered is 10 mOsm/100 cal/day. Maximum excretion of solutes would be 40 mOsm/100 cal/day in instances of rational parenteral fluid therapy except where clinical evidence indicates higher excretion, e.g., diabetes mellitus.

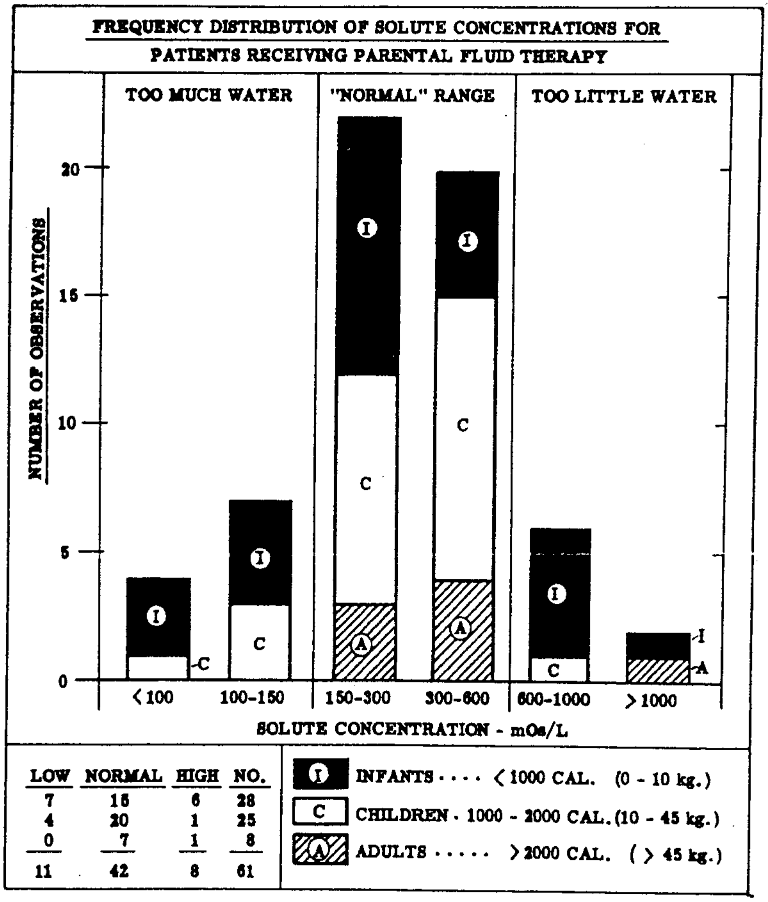
In circumstances encountered in most instances of parenteral fluid therapy, glomerular filtration rate is not greatly reduced and rate of excretion of solutes is not greatly increased. In these circumstances the limit of dilution with maximum water loading is approximately 75 mOsm/l, representing a fourfold dilution from the concentration of solutes in glomerular filtrate, 300 mOsm/l. If the minimum solute load, 10 mOsm, is excreted at only a twofold dilution, 150 mOsm/l, 66.7 ml of urine (10/150 × 1000 = 66.7 ml) would be required. This would seem to represent an attainable minimum for concentration of solutes of most patients.

Conversely, except with solute diuresis of unusual degree, solutes may be concentrated in the urine of normal subjects to 1200 mOsm/l, a fourfold concentration of glomerular filtrate.

Taking a twofold concentration, 600 mOsm/l, as the maximum safe concentration to expect of patients receiving parenteral fluid therapy, the maximum solute load of 40 mOsm/100 cal/day excreted at this concentration would require 66.7 ml (40/600 × 1000 = 66.7). The minimum solute load excreted at 150 mOsm/l requires the same volume of water as the maximum solute load excreted at 600 mOsm/l. This of course derives from the fact that the high concentration of solutes is four times the low and the maximum solute load is four times the minimum. The average solute load, 25 mOsm/l excreted in 66.7 ml of water would be excreted at a concentration of 375 mOsm/l (25/66.7 × 1000 = 375 mOsm/l). Providing 66.7 ml of water for renal excretion for patients receiving parenteral fluid therapy permits the predicted solute loads of 10 to 40 mOsm/100 cal/day to be excreted between the concentrations of 150 and 600 mOsm/l, and the average solute load of 25 mOsm/100 cal/day to be excreted at a concentration of 375 mOsm/l.

To test this concept, the concentration of solutes in the urine was determined in infants, children and adults who had been receiving parenteral fluid therapy for at least 12 hours. The subjects were on various hospital services and their intake of fluid was dictated by the individual service. A random, untimed specimen of urine was obtained. Urine was collected and preserved with thymol. Concentration of solutes was determined in a Fiske osmometer and concentration of creatinine by the method of Folin and Wu.[15]

The data, with respect to concentration of solutes, are represented in Figure 2 in the form of a frequency distribution. This figure is subdivided into three categories arbitrarily defined, as indicated, to represent values pertaining to infants, children and adults. Concentrations of solutes were



LOW	NORMAL	HIGH	NO.
7	15	6	28
4	20	1	25
0	7	1	8
11	42	8	61

FIG. 2.

within the "normal" range in the urine of seven of the eight adults. Concentrations in 4 of the 25 children were low, and only one was high. The concentrations in 13 of the 28 infants were outside the "normal" range. The deviations from "normal" could arise either from erroneous sampling due to variability in rate of administration of fluid, from solute excretions outside the estimated limits, or from improper administration of water. A sampling error of this type is least likely to occur in the infants in whom therapy was generally provided at a constant rate over the 24-hour period.

Since the deviations were greatest in infants, efforts were made to estimate the quantity of solutes excreted during a 24-hour period, thus providing a means of comparing the theoretically estimated values for excretion of solutes to observed values. From a measurement of the daily excretion of creatinine, the expected daily excretion of solutes was computed. A sample calculation is illustrated in Table V. The daily excretion of creatinine was determined in unpublished observations on infants receiving either glucose or human milk and found to be 10.7 mg/kg/day.[13] This figure agrees well with the figure of Marples and Levine[16] for infants receiving diets low in protein (11.6 mg/kg/day). The rate of excretion of solutes computed in this manner averaged 19.5 mOsm/kg/day. In the present system, this would be 19.5 mOsm/100 cal/day since, for the infants included, an infant weighing 1 kg expends 100 cal. A range of 9.9 to 39 mOsm/100 cal/day was observed. This coincides quite well with the theoretic calculations concerning excretion of solutes. The validity of such calculations is admittedly doubtful, for excretion of creatinine from hour to hour and from infant to infant is constant only within broad limits. Furthermore, excretion of creatinine has not been observed under the circumstances of parenteral fluid therapy. In spite of these limitations, we infer from the data that excretion of solutes falls roughly within the theoretically determined limits. If this is the case, it is then necessary to conclude that administration of water was improper in a significant number of infants.

In the case of children and adults, a similar calculation to determine the rate of excretion of solutes was not possible since excretion of creatinine in the child and adult varies even more than it does in the infant, at least in relation to weight or any function of energy metabolism predicted from weight.[17]

The data does imply that the amount of fluid actually given the individuals studied did not consistently permit excretion of solutes within a safe concentration range as it imposed demands on dilution and concentration of solutes which might well exceed individual capability.

As excretion of water is a slow, continuing process, the desirability of regulating the rate of administration of fluids in order that large loads of water are not given in short periods of time should be mentioned. An example might serve to illustrate this point. An infant weighing 3 kg is assumed to have a total daily need for water of

TABLE V

AN EXAMPLE ILLUSTRATING METHOD OF CALCULATION OF TOTAL DAILY EXCRETION OF SOLUTES

Daily excretion of creatinine = 10.7 mg/kg/day (assumed—see text)
Concentration of solutes = 550 mOsm/l (by determination)
Concentration of creatinine = 301 mg/l (by determination)
$\frac{\text{Conc. solute}}{\text{Conc. creatinine}} = \frac{550}{301} = 1.82$ mOsm/mg creatinine excreted
Solute excretion = 10.7 mg creatinine/kg/day × 1.82 mOsm/mg creatinine = 19.5 mOsm/kg/day
1 kg in this range = 100 calories
Solute excretion = 19.5 mOsm/100 cal/day

300 ml (100 ml/100 cal) and a total daily excretion of solutes of 75 mOsm (25 mOsm/100 cal). The rate of excretion of solutes would then be about 3 mOsm/hr. At maximal urinary dilution (75 mOsm/l) the maximal rate of excretion of water would be 40 ml/hr (13.3 ml/mOsm). Should half the daily need for water, 150 ml, be given in a 1-hour period, the excretion could then be but 40 ml. The insensible loss of water in that hour would account for an additional 6 ml. The balance, 104 ml, would be retained. The total quantity of water in the body is estimated to be 1800 ml (60% of the body weight). The addition of 104 ml of water would represent a dilution of body fluid of nearly 6% and would result in a drop of approximately 8 mEq in the concentration of sodium in the serum. Such an abrupt decrease in concentration of sodium is sufficient to produce symptoms. Furthermore, under stimulus for maximal excretion of water the administered water would be excreted in a 4-hour period and, unless this were taken into account, a period of relative water deficit would then ensue.

Daily administration of water is then best provided continuously, but certainly it should be provided over a period of at least 12 hours. This is especially true in the infant. The significant number of infants excreting urine at concentrations less than 100 mOsm/l indicates that the above considerations are often ignored. Excessive amounts of glucose and water are frequently given to "maintain an infusion." The inherent danger of such practices is evident from the foregoing consideration.

Equally apparent is the fact that insufficient amounts of water were provided in 6 of the 28 infants, and a fairly extreme degree of concentration of solutes in the urine resulted. Such circumstances, obviously, may lead to production of significant deficits of water and to dehydration.

In summary, the losses of water of an individual consist of the insensible loss and the urinary loss, stool losses being negligible. From the considerations given here, the average figure for total loss of water is 116.7 ml/100 cal/day. It is fair to assume that the water of oxidation will provide nearly 16.7 ml.[10] The balance, 100 ml/100 cal/day, must be provided parenterally. Fortuitously then, average needs for water expressed in milliliters equals estimated energy expenditure in calories.

MAINTENANCE ELECTROLYTE NEEDS

With respect to maintenance needs for electrolyte, less precise data are available, and figures considerably in excess of the minimum requirements are readily handled. This fact is apparent in comparing the electrolyte intake of infants receiving human milk and cow's milk. The intake of electrolytes in relation to the intake of calories for babies receiving each type of milk is indicated in Table VI. Also presented are the figures recommended by Darrow[1] for infants and adults, and by Welt[11] for adults, recalculated in terms of 100 cal. Close agreement of the various systems is evident. It is also apparent that these values fall between the intakes provided by human milk and cow's milk and should therefore be acceptable as maintenance needs for electrolyte.

TABLE VI

INTAKE OF ELECTROLYTES PROVIDED PER ESTIMATED 100 CALORIES ON VARIOUS REGIMENS

Regimen	*mEq/100 cal/day*		
	Na	*Cl*	*K*
Human milk*	1.0	1.2	2.0
Cow's milk	3.5	4.5	6.0
Recommended†	3.0	2.0	2.0
Recommended (Darrow)	3.0	2.0	3.0
Recommended adult**	3.0	3.0	1.0

* Computed assuming an intake of 150 ml/100 cal/day which provides 100 cal.

† May be added to glucose and water using 3 ml of molar sodium lactate and 1 ml of 2 molar potassium chloride for each 100 ml of maintenance fluid.

** Adult values from Welt.[11] Administration of 500 ml of normal saline per day provides 75 mEq of sodium and chloride total. Potassium administration of 30 mEq/day is recommended. The figures per 100 cal are calculated assuming adult calorie expenditure to be 2500 cal/day.

CONCLUSION

In presenting a simple and arbitrary scheme for computing calories from weight, it is recognized that significant deviations from this relation exist. Excessive obesity, the declining metabolism of the aged, and the increased metabolism of patients with infection, all may require modifications of the scheme. Infants during the first 10 days of life, have a metabolic rate 20 to 30% less than that cited here. As with any method, an understanding of the limitations of and exceptions to the system are required. Even more essential is the clinical judgment to modify the system as circumstances dictate.

With respect to the general applicability of the average figures for water intake per 100 calories, it is evident that specific clinical situations dictate alterations. Hyperventilation may double the insensible losses of water, and glycosuria or excessive excretion of nitrogen may double renal losses of water. Obviously, in anuria losses of water are decreased and administered fluids should replace only the insensible loss of water plus the measured volume of urine excreted. Simple observations of the clinical status may dictate a modification from the average values of this or any other system. Finally, it should be emphasized that these figures provide only maintenance needs for water. It is beyond the scope of this paper to consider repair of deficits or replacement of continuing abnormal losses of water. These must be considered separately and must be added to the needs for maintenance.

SUMMARY

It is generally agreed that the maintenance requirements for water of individuals is determined by their caloric expenditure. By means of the following formulae, the caloric expenditure of hospitalized patients can be determined from weight alone. For weights ranging from 0 to 10 kg, the caloric expenditure is 100 cal/kg/day; from 10 to 20 kg the caloric expenditure is 1000 cal plus 50 cal/kg for each kilogram of body weight more than 10; over 20 kg the caloric expenditure is 1500 cal plus 20 cal/kg for each kilogram more than 20.

Maintenance requirements for water depend upon insensible loss of water and renal loss. An allowance of 50 ml/100 cal/day will replace insensible loss of water, and 66.7 ml/100 cal/day will replace the average renal loss so that the total requirement is 116.7 ml/100 cal/day. As water of oxidation will supply approximately 16.7 ml/100 cal/day, the remaining 100 ml/100 cal/day must be supplied to meet the remaining water losses of patients on parenteral fluid therapy. Possible exceptions to this figure are discussed.

Maintenance requirements of sodium, chloride and potassium are 3.0, 2.0 and 2.0 mEq/100 cal/day, respectively.

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