Nitrogen Balance *as Related to* Caloric and Protein Intake *in* Active Young Men

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THE physiologic effects of restricted feeding, particularly on protein utilization, have occupied the interest of nutritionists since the time of Voit and Rubner.[19] Impetus for experimental investigation of the problem has been lent, historically, by periods of war and catastrophe when national food supplies are critical. In recent years, this problem has warranted the particular attention of nutritionists in the Department of Defense because of the recognition of situations of limited feeding capabilities created by modern mobile warfare. In this category fall troops cut off from normal supply channels, especially victims of air and sea disaster, and civilian populations of disrupted areas. Under military support, many data have been gathered which have not been widely available to scientists and have not been consolidated with other clinical and laboratory findings. As an aid in the design of a multipurpose survival ration, the information relative to normal active men in the military age group has been compiled, emphasis being placed on the more acute, short-term experiments.

The information on nitrogen balance in chronic inanition has already been critically reviewed by the Minnesota group,[18] and that relating to protein-depleted man by Benditt and co-workers.[2]

SELECTION OF DATA

Studies were chosen from the literature in which the subjects were young men, essentially normal in weight and nutritional status, who were permitted at least sedentary activity. Data on control groups indicate that the men normally maintained body weight at intakes of 3000 to 3600 calories per day. Estimates of caloric expenditure during the restriction phase ranged between 2000 and 3500 calories daily. Only two representative reports in the area of adequate caloric intake were chosen from the wealth of material available,[5, 11] one at a low protein level, and a second where the protein allowance was liberal. Included are military field trials and laboratory studies of military personnel, college students, Civilian Public Service Camp workers, and conscientious objectors.

It has been recognized that continued dietary restriction ultimately results in adaptation to a lowered intake of protein[12] or of calories.[18] However, in the caloric intake range 1500 and above, some long-term studies were drawn upon because of the dearth of other information; where these investigations had to be included, only the data from the first two weeks were used.

Many reports were excluded from this survey because of inadequate quantification of dietary intakes, questionable values for excretion, or simply because insufficient data were provided. Also excluded from consideration were experimental findings in frankly obese individuals, in men at bed rest, and in those fed parenterally.

If feces were not analyzed for nitrogen content, arbitrary allowances were made. Where

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TABLE I

Nitrogen Balance in Protein-free Feeding

Caloric intake		Nitrogen balance			
Range*	Composite mean	Range*	Composite mean	Number of observations	References
Cal./day	*Cal./day*	*Gm./day*	*Gm./day*		
0	0	−7.9 to −13.0	−12.0	87	3†, 4, 6, 7, 14, 22, 27, 39, 40
31–200	119	−9.1 to −11.1	−10.9	17	6, 8, 40
400–500	441	−6.6 to −9.4	−8.4	22	6, 13, 17, 22, 40
669–787	728	−7.0 to −7.4	−7.2	10	33, 34
800–958	891	−6.3 to −7.8	−7.2	34	6, 24, 25, 29, 30, 32, 35
—	1200	—	−7.3	2	6
—	1443	—	−6.3	5	36
—	2400	—	−7.4	1	38
—	2800	—	−6.8	8	7

* Range of experimental means.

† Including literature reviewed.

protein-free diets or protein-containing diets of less than 1000 calories per day were fed, one gram of nitrogen—the average value of fecal analyses reported—was added to the excretion. When protein was fed and the caloric intake was above 1000, the correction figure of 1.28 grams was used, as suggested by Reifenstein, *et al.*[26]

A composite mean for all the experiments within a stated range of caloric and protein intake was derived by weighting the mean of each experimental group for the number of subjects observed. As the majority of reports did not include data on daily nitrogen excretions, the composite means were derived from the average values for the periods of restriction tested. Although nitrogen excretions during the first two days of the experimental period reflect primarily the influence of preceding protein intake, the mass effect during an average restriction period of ten days was not significantly altered by the inclusion of this early period, inasmuch as the preceding equilibration diet in all cases furnished a normal intake of protein. Examination of individual studies shows wide variation among subjects and between means of related experiments. The summations should be viewed in this light.

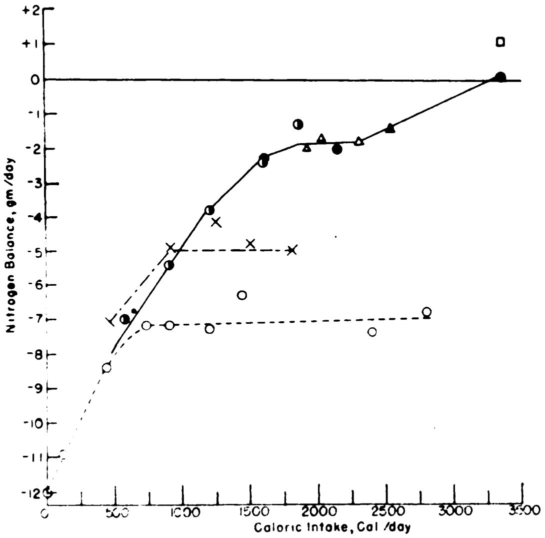

Fig. 1. Nitrogen balance at various levels of caloric intake.

○ Protein-free followed by Nitrogen intake, Gm./day: ⟍ 1.0–1.9, × 2.4–5.0, ◑ 5.4–7.7, ● 8.1–9.7, △ 10.4–11.7, ▲ 12.4, □ 15.4.

Interrelationships of Protein and Caloric Limitation

To establish a baseline for determination of nitrogen utilization, consideration must first be given to the excretion of nitrogen when none is fed. These data are presented in Table I and are shown graphically in Figure 1. Nitrogen losses amounted to 12 grams daily in fasting, and the protein deficit was maximally reduced by supplying approximately 700 protein-free calories. Increasing the caloric intake to 2800 was without further advantage in the sparing

TABLE II

Nitrogen Balance at Varying Caloric and Nitrogen Intakes

Caloric intake		Nitrogen intake		Nitrogen balance			
Range*	Composite mean	Range*	Composite mean	Range*	Composite mean	Number of observations	References
Cal./day	*Cal./day*	*Gm./day*	*Gm./day*	*Gm./day*	*Gm./day*		
400–500	467	1.0–1.9	1.6	−6.5 to −8.2	−7.1	6	17
—	572	—	6.9	—	−7.0	2	6
803–1100	911	2.4–4.5	3.1	−3.2 to −7.4	−4.9	60	14, 20, 29, 30, 31, 32
754–1023	891	5.4–7.7	6.3	−1.6 to −7.9	−5.4	50	24, 25, 27, 30, 32, 33, 34, 35
1200–1331	1256	3.0–5.0	4.5	−1.1 to −6.8	−4.1	25	13, 30, 31
—	1200	—	6.0	—	−3.8	4	30
—	1500	—	3.0	—	−4.8	4	30
1432–1638	1587	6.0–7.6	7.2	−2.0 to −4.5	−2.4	15	5, 18, 30
1522–1650	1596	8.1–9.7	8.9	+0.2 to −4.8	−2.3	36	5, 16, 20, 36
—	1800	—	3.0	—	−5.0	4	30
1800–1948	1854	6.0–7.4	6.6	−0.3 to −3.8	−1.3	33	20, 27, 30, 31, 32
1919–1962	1924	10.4–11.7	11.5	−1.4 to −2.1	−2.0	48	5, 21
2140–2146	2143	8.1–8.2	8.2	−1.8 to −2.1	−2.0	6	14, 27
2028–2135	2030	10.8–11.6	11.5	−1.7 to −2.1	−1.7	49	5, 21
2268–2330	2299	11.1–11.4	11.2	−1.6 to −2.0	−1.8	12	5
2521–2532	2526	—	12.4	−1.3 to −1.5	−1.4	86	21
—	3355	—	8.5	—	+0.1	8	11
—	3342	—	15.4	—	+1.1	12	5

* Range of experimental means.

of body protein, the negativity of nitrogen balance remaining approximately 7 grams throughout.

From Table II and Figure 1 it is apparent that feeding nitrogen to the highest level tested, 6.9 grams daily, was of little benefit when only 400 to 600 calories were supplied. The mean daily negative balance of 7.0 grams of nitrogen falls well within the range of means obtained when no protein was fed. It is apparent that protein fed under these circumstances is largely burned as an energy source, producing a concomitant rise in urinary nitrogen excretion.

An intake of approximately 900 calories was the lowest level at which the addition of protein to the diet produced noticeably less negative nitrogen balance than the same number of protein-free calories. At this calorie level the same reduction in negativity of nitrogen balance occurred with 3 grams as with 6 grams of nitrogen fed. When dietary nitrogen was limited to 3 grams per day, maximum nitrogen retention was attained at approximately 900 calories, and increasing the caloric intake to 1800 did not further reduce the 5 grams of negative balance.

Increasing the energy value of the diet from 900 to 1600 calories when 6 grams or more of nitrogen were fed resulted in improved nitrogen retention. A plateau at 1.8–2.4 grams of negative nitrogen balance was reached at approximately 1600 calories, which persisted through approximately 2300 calories. The plateauing trend over a wide range of both nitrogen and caloric intakes suggests that in this range of 50 to 75 per cent of normal caloric requirement, adjustment of energy expenditure to intake may have taken place so that a relatively constant fraction of actual requirement was met.

On the basis of the 7 grams of total nitrogen excretion which was the baseline for protein-free feeding, it is logical to assume that no increase in the energy content of the diet could promote nitrogen balance when the nitrogen intake is below this amount. The lowest nitrogen intake tested at adequate caloric intake in subjects defined here was 8.5 grams of nitrogen daily; at this intake, nitrogen equilibrium was obtained. At nitrogen intakes of 11 to 12 grams daily, calories were limiting through 2500. These data are in good agreement with the critical value for protein utilization of 1500 calories/M^2 surface area/day derived for protein-depleted men by Benditt and coworkers,[2] and the 35–40 calories/Kg. established in severely undernourished subjects by Beattie *et al.*[1] Beyond this range, these authors state, the nitrogen intake determines the sign and magnitude of nitrogen balance.

The effect of caloric intake on nitrogen balance may then be described by Figure 1, in which the slope of the line is determined by caloric limitation with plateaus related to nitrogen deficit.

In Figure 2, the data are graphed to show the effect of variation in nitrogen intake on nitrogen balance. It is apparent, as previously discussed, that at calorie levels of 400–600, dietary nitrogen is without appreciable benefit. When the caloric intake is approximately 1000, 3 grams of nitrogen may be used to good advantage, but further increase is without benefit. At calorie levels of 1400–2300, 7–9 grams of nitrogen result in essentially the same sparing of body protein as intakes to 12 grams. Between 2300 and 3300 calories, data are insufficient to permit analysis, but the slope of the line indicates that equilibrium might be attained at the 2000–2500 calorie level if the

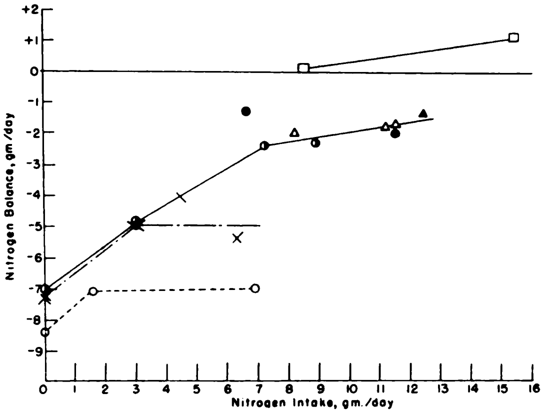

Fig. 2. Nitrogen balance at various levels of nitrogen intake.

Calorie intake cal./day: ○ 400–575, × 750–1100, \1200–1350, ◑ 1400–1650, ● 1800–1975, △ 2025–2350, ▲ 2530, □ 3350.

nitrogen intake were increased to approximately 24 grams. Sargent and Johnson[28] in a preliminary oral report of recent studies stated that positive nitrogen balance was approached in a subject fed 2000 calories and 24 grams of nitrogen.

When the full caloric requirement was met, 8.5 grams of nitrogen were sufficient to promote balance, and increasing the intake to 15.4 grams resulted in retention of only an additional gram of nitrogen. Cuthbertson and Munro[9] have reported that the addition of 780 calories to a diet adequate for maintenance reduced urinary nitrogen excretion by 2 grams. A luxus consumption, then, of either protein or calories resulted in more positive nitrogen balance, just as an inadequate intake of either produced a negative balance.

To the general principles set forth—that on a fixed adequate protein intake, energy level is the deciding factor in nitrogen balance and that with a fixed adequate caloric intake, protein level is the determinant—may be added a corollary. That is, at each fixed inadequate protein intake there is an individual limiting energy level beyond which increasing calories without protein or protein without calories is without benefit. Why 600–800 dietary calories should maximally reduce the destruction of body protein but not permit the utilization of dietary protein, or why 3 grams of dietary nitrogen should be most efficiently used at 1000 calories, or 6 grams at 1600, are intriguing questions for which there are no ready answers.

Application

The findings reviewed here provide a basis for the development of a protein-containing military survival ration and the conclusions apply equally to short-term civilian emergency feeding. However, the most critical situation to be considered is that in which water supply is curtailed and the weight or space available for emergency food highly restricted, as in survival at sea or in the desert. Under these conditions provision of about 100 grams of carbohydrate, as suggested by Gamble,[15] is physiologically most desirable. It was shown that the benefits to be derived are several: prevention of ketosis, conservation of body fluid and protein with extension of survival expectancy beyond that of fasting, and a large contribution to morale. Inclusion of protein in such a restricted ration is contraindicated from the standpoint of water balance. The two effects of increasing dietary protein when energy levels are inadequate are demonstrated in Figure 3: a small decrease in nitrogen deficit accomplished at the cost of increasing urinary nitrogen excretion and obligatory urine volume. Assuming maximum renal concentration, the excretion of one gram of urea nitrogen requires 40 to 60 cc. of water.[37] The inclusion, then, of 6 grams of dietary nitrogen in a 500-calorie diet increases the volume required for renal excretion by 250 cc. per day—50 cc. more than fasting requirements.

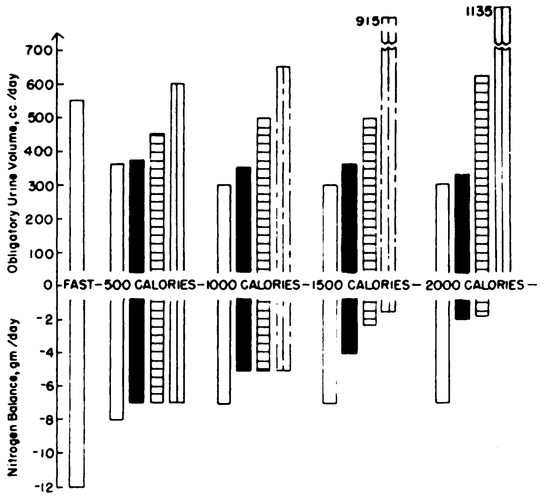

Fig. 3. Calculated alteration in obligatory urine volume compared with nitrogen deficit at varying intakes of protein and calories.

	Protein	
	% of cal.	Gm./500 cal.
□	0	0
■	7.5	9–10
⊟	15	18–20
◫	30	36–40

The relationships between protein and caloric intake seen in Figures 1 and 2 suggest the formulation of a versatile food unit of 500 calories, 7 to 8 per cent of which are derived from protein. Such a unit could then be consumed in any multiple number with maximum benefit from the protein at each energy level. The efficacy of this scheme is illustrated in

Figure 3; it is apparent that increasing the protein intake beyond the suggested unit level results in little or no additional sparing of body tissue protein.

The composition of the diet is apparently not critical. Schwimmer[32] reported that a 30 per cent fat diet was more effective in promoting nitrogen utilization than one containing 10 per cent. The results of the many studies included here do not support this conclusion. Munro,[23] in an exhaustive review of the literature, concluded that there is essentially no difference between carbohydrate and fat in this regard. Sufficient carbohydrate should be provided to prevent ketosis and the amount of fat determined by considerations of caloric density and palatability. The diet should be of uniform composition to achieve maximum benefit of the protein fed in view of the time factor in utilization.[10]

The unit system offers distinct advantage over a set ration allowance in that it may be readily adjusted in consideration of: (1) the level of energy expenditure, (2) the number of people to be fed from the supply available, and (3) the length of time before resupply may be effected.

SUMMARY

Based on an intensive review of published observations on protein intake in the presence of a reduced caloric intake, certain conclusions seem clear.

For young, essentially normal active men, when no protein is fed the protein deficit (negative nitrogen balance) can be maximally reduced by supplying about 700 nonprotein calories. No significant protein-sparing is achieved by intake as high as 2800 calories in the absence of protein. When the caloric intake is approximately 1000, 3 Gm. of nitrogen will produce as much protein sparing as higher quantities of nitrogen. When full caloric requirement is met, 8.5 Gm. of nitrogen promotes balance and little additional storage results even from much larger protein intakes.

These findings, plus others cited from the literature, suggest that a versatile food unit of 500 calories (7 to 8 per cent of which are derived from protein) would be most practical and physiological in the development of a military survival ration, or a short-term civilian emergency feeding.

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RESUMEN

El equilibrio nitrogenado en relación con el consumo calórico y proteico en jóvenes activos

Parece que ciertas conclusiones bastante claras puedan deducirse de una revista intensiva de las observaciones publicadas sobre el consumo proteico en la presencia de un consumo reducido de calorías.

En los hombres jóvenes, activos y esencialmente normales, cuando se les priva de toda proteína, el déficit proteico (equilibrio negativo de nitrógeno) se puede reducir al máximo por la suministración de unas 700 calorías no proteicas. Ningún efecto significativo de ahorro de proteínas se logra por una ingestión de hasta 2800 calorías. Cuando el consumo de calorías se aproxima a 1000, se logra con 3 gramos de nitrógeno un ahorro de proteínas tan grande como el conseguido con cantidades mayores de nitrógeno. Cuando se cumple el requerimiento total de calorías, el equilibrio se logra con 8,5 gramos de nitrógeno, y no se consigue mucho almacenaje adicional ni con ingestas mucho mayores de proteína.

Estos hallazgos, con otros citados de la literatura, sugieren que una unidad alimenticia versatil de 500 calorías (7 a 8 por 100 de las cuales serían derivadas de la proteína) sería fisiológica y resultaría muy útil en la confección de una ración de sustinencia para los militares o de un alimento para los civiles en períodos de crisis o desastre.