Undersea Biomedical Research, Vol. 19, No. 4, 1992

Evaluation of energy requirements from body mass, lean body mass, fat content, and energy intake in GUSI dives

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Busch-Stockfisch M, von Böhlen B. Evaluation of energy requirements from body mass, lean body mass, fat content, and energy intake in GUSI dives. Undersea Biomed Res 1992; 19(4):263–270.—This study reports the changes in body composition measured during 6 deep saturation dives, the depths and the working hours performed during the dives, and the effects of these parameters on the energy requirements. Changes in lean body mass could be avoided if the working days amounted to 40–45% of the total dive time. Energy requirement depended not only on working days but also on the diving depth. Physical work at great depth requires a disproportional increase in the energy requirements beginning between 200 and 360 m. Under working conditions at 450 msw, energy requirements increased about 30% relative to the total energy needs under normal conditions.

energy requirements
lean body mass
body fat content

During simulated deep saturation trimix dives in the German underwater simulator (GUSI), the divers were subjected to physiologic and psychologic stress. Nutritional field studies have been performed since 1985 during 6 of these deep saturation dives to gather nutritional data and thus design an adequate diet for future divers.

The studies were performed at depths between 200 and 600 msw (Table 1) with 3 or 4 subjects (1–6). The data collected included nutritional habits and anthropometric changes in the divers. Preferences for special dishes and the nutritional habits of the divers often made it difficult to prepare an optimal nutritional protocol.

A literature review shows that little research has been performed in this area (7, 8). Presently the only nutritional studies being done are these at GUSI.

METHODS

Subjects

The studies for each of the 6 dives were performed by 3 or 4 divers aged 26–42 yr (mean 32.5). Anthropometric measurements of body weight; body mass; and skinfold

TABLE 1

AVERAGE BODY MASS BODY FAT CONTENT AND LEAN BODY MASS

	Average Body Mass in kg		Average Body Fat Content				Average Lean Body Mass			
			Predive		Postdive		Predive		Postdive	
Dive	Predive	Postdive	in kg	in %	in kg	in %	in kg	in %	in kg	in %
GUSI 6	74.0	70.8	11.3	15.2	10.5	14.8	62.7	84.8	60.2	85.2
GUSI 7	82.5	79.6	14.9	18.0	13.5	16.9	67.6	82.0	66.1	83.1
GUSI 8	86.4	81.0	14.1	16.3	13.3	16.4	72.3	83.7	67.7	83.6
GUSI 10	83.9	81.3	14.9	17.8	13.5	16.5	69.0	82.2	67.9	83.5
GUSI 12	80.3	80.4	12.4	15.4	11.6	14.4	67.9	84.6	68.8	85.6
GUSI 14	85.9	84.1	15.5	18.1	15.8	18.8	70.4	82.0	68.3	81.2

thickness of the upper arm, thigh, and calf were made. Body fat content was calculated from skinfold thicknesses with the following formula (9):

$y = -16.2 + 9.367 \lg x_1 + 13.462 \lg x_2 + 5.298 \lg x_3$
y = body fat content in percent of total body weight.
x_1 = skinfold thickness at triceps, mm
x_2 = sum of skinfold thickness subscapular and anterior axillary border, mm
x_3 = skinfold thickness at the abdomen
K = Lean body mass (LBM) was calculated by (9): LBM = body mass, kg − body fat content, kg

Measurements were performed 1 day predive and postdive, except body mass, which was measured once a week in the first 3 dives and daily in later ones. Skinfold measurements were performed using a Holtain skinfold caliper.

Daily food intake was measured for every diver individually, using a modified form of the precise weighing method (10, 11) and calculations from nutrition tables (12). In general, this method is considered the most precise one for nutritional surveys. It was modified so that the values obtained were more precise than those derived from the original method. It is very time- and personnel-consuming, requiring the attendance of the investigators throughout the measuring period of 32 or more days per dive. The divers were allowed to request their favorite foods, but had to be very disciplined in their diets because they were allowed to eat only the food provided for them and they have to eat under controlled conditions. The most precise results are achieved when the investigators prepare the food and give it to the divers, while motivating them to eat carefully. Leftover food was weighed and recorded (11). This method has been applied during all the dives discussed here.

Estimate of energy and nutrient requirements

Basal metabolic rate was calculated daily for every diver according to Kleiber (13).

$B = 71.2\,W\,[1 + 0.004\,(30\text{-}A) + 0.010\,(S\text{-}43.4)]$
B = Basic metabolic rate in kcal/day
W = Body mass in kg
A = Age in years
S = Specific body height in cm $\times$ kg

The metabolic rate for physical activity such as surface welding was added to the basic resting data. Welding has been calculated to be exceptionally active work, assuming 840 kJ/h. Individual working hours per day were taken into consideration, and standby working time was calculated as off-duty time at 157 kJ/h. Six percent of total energy demands were assumed to be the specific dynamic effect and 6% as energy loss via urine and feces (13, 14).

RESULTS

In all dives, body weight decreased markedly during the first 10–20 days of the dive. During the following phase, weight was relatively constant, with slight decreases or increases. Weight losses that continued beyond Day 20 were found only in very deep dives, GUSI 6 at 450 m, GUSI 7 at 500 m, and GUSI 8 at 600 m (Fig. 1).

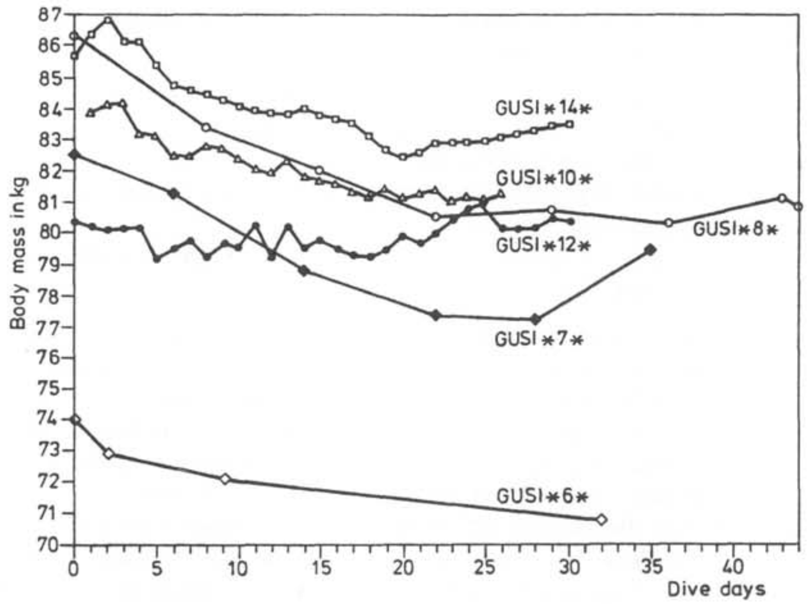

Fig. 1. Average body mass during the dives.

During the 5 previous dives a decrease of body fat content was found, but in GUSI 14 an increase occurred for the first time (Table 2). In GUSI 6, divers had the lowest predive body fat content at 15.2%. In GUSI 14, the highest body fat content was measured predive at 18.1%, and although body weight decreased, relative and absolute body fat content increased during the dive. A similar phenomenon was found in GUSI 8, in which only the relative fat content of the subjects increased, although body mass decreased.

In all dives except GUSI 12, lean body mass decreased (Table 2). During GUSI 12, lean body mass increased. The relative proportion of lean body mass in all dives increased except in GUSI 8 and 14, where the losses were very small. Table 3 shows lean body mass pre- and postdive, the portion of the total body weight in percent and

TABLE 2

DURATION OF THE DIVES (DAYS), NUMBER OF DAYS AT WORK, PERCENTAGE OF DAYS AT WORK TO TOTAL DAYS

Dive	Depth, m	Duration	Days at Work	Percent Work/ Total Days
GUSI 6	450	32	10	31.3
GUSI 7	500	35	9	25.7
GUSI 8	600	44	4	9
GUSI 10	360	26	10	38.5
GUSI 12	200	30	21	70
GUSI 14	450	34	12	35.3

TABLE 3

AVERAGE ENERGY INTAKE, ENERGY REQUIREMENTS AND CALCULATION OF AN EFFECTIVE ENERGY REQUIREMENT OUT OF ENERGY INTAKE, BODY FAT AND LEAN BODY MASS CHANGE, 6% SDW, 6% LOSS WITH URINE AND FECES

Dive	Theoretical Average Energy Requirement Under Normal Conditions, kJ (1)	Average Energy Intake, kJ (2)	Energy Content of Body Fat Changes, kJ (3)	Energy Content of Lean Body Mass Changes, kJ (4)	Average per Day 3 + 4, kJ (5)	12% SDW, Urine and Feces Losses, kJ (6[a])	Energy Requirement, kJ (7[b])	Difference to Theoretical Energy Requirement, kJ (8) (7-1)
GUSI 6	11,882	12,191	24,000	17,500	1,297	1,839	15,327	+3,445
GUSI 7	12,655	10,217	42,000	10,500	1,500	1,598	13,315	+ 660
GUSI 8	12,133	11,606	24,000	32,200	1,277	1,757	14,640	+2,507
GUSI 10	13,182	12,145	42,000	7,700	1,911	1,917	15,973	+2,791
GUSI 12	15,081	13,868	24,000	−6,300	590	1,971	16,429	+1,348
GUSI 14	12,669	13,872	−9,000	14,700	167	1,914	15,953	+3,284

[a]12% of the energy requirement; [b]energy requirement (2) + (5) + (6).

the absolute and percentage changes. In all dives except GUSI 12 there was an absolute decrease in lean body mass of various degrees.

Mean energy per week is shown in Fig. 2. During GUSI 7, 8, and 10, energy intakes reached their minimum the 2nd wk, during the 3rd wk in GUSI 6, and in the 5th and 6th wk in GUSI 12 and 14. In most dives, an increase was measured after this minimum, except for GUSI 12 and 14. In GUSI 6, 7, and 8, energy intake during the last week was above that of the first, which in GUSI 6 was probably due to initial problems in providing food, during GUSI 7 due to sickness of the subjects in the 1st and 2nd wk, and in GUSI 8 due to the small amount of work and the length of the dive.

DISCUSSION

Diving depth, duration of the dive, and the proportion of working days have no influence on body weight and body fat changes. A correlation of $r = 0.94$ exists between the percentage of working days within the dives and the percentage change of lean body mass. A correlation coefficient of $r = 0.76$ exists between the duration of the dive and the lean body mass changes. This suggests a relationship between physical activity and duration of the dive on the lean body mass, i.e., muscle mass. An increase of lean body mass during a dive also is possible. This was the case in a dive with a proportion of 70% working days. Little loss of lean body mass was found in GUSI 10 with 38.5% working days. To preserve muscle mass, 40–45% of the total number of diving days have to be days at work. This would also permit maintenance of the physical capabilities of the divers.

A correlation coefficient of $r = 0.93$ exists between diving depth and lean body mass losses, and with increasing diving depth, lean body mass loss increased. With these GUSI dives there was a decrease of the proportion of working days with increasing diving depth, so it can be concluded that the influence of working day rate is most important on the maintenance of the muscle mass.

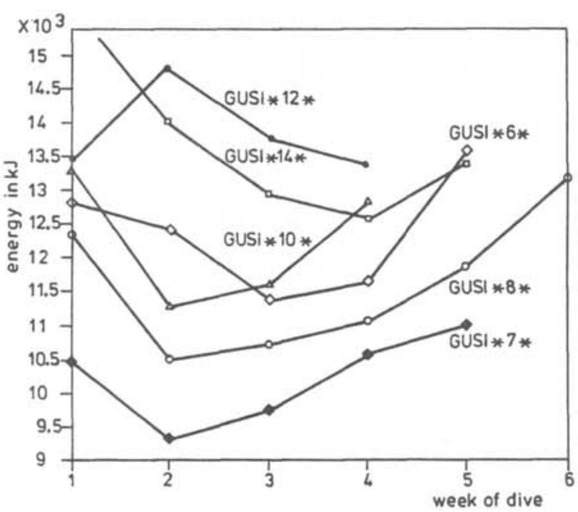

Fig. 2. Average energy intake during GUSI dives 6, 7, 8, 10, 12, and 14.

Energy requirement

Attempts were made to calculate the real energy requirements from energy intake and body mass changes (fat and lean body mass). For the evaluation of body fat losses, the loss or gain of fatty tissue in grams has been multiplied by 30 kJ (Table 3, column 3) and the lean body mass changes by 7 kJ (60% H_2O + 40% protein = 17 kJ/g protein) (Table 3, column 4). Energy requirements between 14.6 and 16.4 kJ were found, which may be reference values for future nutrition to fulfill the energy demands.

If one compares these values with the calculated energy requirements, which take into consideration working and off-duty times under normal conditions (Table 3, column 1), it is shown that except for GUSI 7, the energy requirements (Table 3, column 7) are a function of the hyperbaric workload. The higher the proportion of working time under high pressure, the more the energy requirements surpass the theoretically calculated ones (Table 3, column 8).

In GUSI 6 and 14 the number of working days at 450 m was comparable, and at 360 m in GUSI 6 and 14 there was a greater number of working days. The total and proportional working time at 360 m in GUSI 10 was higher than in the dives mentioned above. Nevertheless, the amount of calculated energy requirement exceeds the theoretical energy requirement less in GUSI 10 than it does in GUSI 6 and 14 (Table 3, column 8).

A greater diving depth with a small amount of working time, as in GUSI 8, gives a smaller increase in the energy requirements than a shallower depth with a greater proportion of working time. This is enhanced because at a diving depth of 200 m (GUSI 12), in spite of double the number of working days, the mean daily energy requirements rise less. We conclude that work at great depth induces an overproportional rise in energy requirement. One might calculate the difference of the energy requirement of 500 kJ in GUSI 10 and 14 as the amount that is needed during the work days at 450 m. For these working days, this would sum to an additional 3500 kJ and to a total energy requirement of 19,450 kJ for work at 450 m. In contrast, calculations for the same work under normal conditions are considerably less. Although intra-individual differences exist, the values of dives in GUSI 6 and 14 are close.

At a diving depth of 450 m, an increase in the average energy requirements of about 30% must be estimated for working days. Moreover, at a diving depth of 200 m the influence on energy metabolism is relatively small because, in spite of the high proportion of working days, the calculated excess in energy requirements is 60% less than at 450 m and 50% less than at 360 m. Between 200 and 360 m there seems to be a threshold beyond which energy requirements rise disproportionately.

Manuscript received July 1991; accepted April 1992.

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