Dietary Support of Long-Duration Head-Down Bed Rest

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Introduction: Dietary control and nutrient intake are critical aspects of any metabolic study, but this is especially true in the case of bed rest studies. We sought to define nutritional requirements, develop menus, and implement them during long-duration head-down bed rest studies. ***Methods:*** The dietary goals were to provide 100% of subjects' nutrient requirements and to maintain subjects' bodyweight to within 3% of their weight on the third day of head-down bed rest. The research dietitian and metabolic kitchen staff are an important part of the multidisciplinary team required to implement a bed rest study. ***Results:*** We report herein the planning steps and nutrient intake results from 13 subjects. We also provide insight into some of the dietary challenges that arise during long-duration bed rest studies. ***Discussion:*** Regardless of the overall objective of the bed rest study to be performed, nutrition must be carefully planned, implemented, and monitored to prevent results from being compromised.
Keywords: nutrition, food support, menu planning, bed rest.

NUTRITION AND DIETARY support are critical components of any bed rest study. Food is very important to subjects who are confined to the research unit for almost 4 mo, and sometimes diet issues determine whether subjects complete the study. In addition to caloric and nutrient content, care taken with respect to palatability, variety, and individual food preferences is critically important to a successful dietary strategy. The study described in this issue had two overall dietary goals: 1) to provide subjects with 100% of their nutrient requirements; and 2) to maintain bodyweight within 3% of bodyweight on the third day of head-down bed rest. This report is one of a series of reports on the NASA Flight Analogs Project (FAP), which is designed to lay the groundwork for a standard bed rest protocol. There are several approaches to standardization of bed rest diets. For the FAP study, an isocaloric diet was chosen. This report describes the approach and results.

METHODS

Study methods were described by Meck et al. (13). Bed rest and test protocols were reviewed and approved by the Johnson Space Center Committee for the Protection of Human Subjects, the UTMB Institutional Review Board, and the UTMB General Clinical Research Center Science Advisory Committee. Subjects received verbal and written explanations of the bed rest and test protocols before providing written informed consent.

Before the study began, the dietitian identified all dietary requirements and constraints, including food allergies and intolerances of the test subjects, and then developed the menus. Before entering the study, subjects were provided with sample menus. Subjects were instructed to identify foods to which they had allergies and foods that they would not tolerate. The dietitian then met with each subject to discuss food preferences and to get a better understanding of why certain foods were not acceptable. During this time, it was explained that menus were standardized, but that minor allowances would be made to accommodate subjects with adverse reactions to certain foods. Subjects were informed that: a) all meals would be prepared in the metabolic kitchen; b) they were expected to eat 100% of all meals; c) no other food items were allowed in the rooms; and d) visitors were not allowed to bring food into subjects' rooms. The dietary preference forms were then signed by the subject and the dietitian upon agreement that the subject understood the dietary expectations. During the study, the dietitian interacted daily with subjects to discuss dietary issues and make adjustments, if possible; monitored weights; and encouraged subjects to comply with the requirement to consume all food. The dietitian also worked closely with the nursing staff to resolve any dietary issues related to the medical care of the subjects. The research dietitian also oversaw the staff of the metabolic kitchen in the preparation of the meals, tracked caloric and nutrient intake for each subject via the nutrition database, and performed analysis of nutrient intake data.

Subjects and Study Design

A total of 13 healthy subjects (8 men, 5 women) participated in the study. The mean (± SD) age of the 13 subjects was 35.5 yr ± 9.6. The subjects had an average height of 168 cm ± 9, and weighed 72.6 kg ± 16.2. The study had three phases: pre-bed rest, an ambulatory

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acclimation and baseline data collection period; bed rest, 60-90 d of continuous head-down bed rest; and a post-bed rest rehabilitation and recovery phase.

Nutrient Requirements

The study diet was designed to approximate the nutrient content provided to astronauts during spaceflight (10). At baseline, its composition was 55% carbohydrates, 30% fat, and 15% protein. Dietary constraints included no caffeine, cocoa, chocolate, tea, or herbal beverages. Caloric requirements were individualized for each subject. The Harris-Benedict Equation (4) for calculation of resting energy expenditure was used to estimate caloric intake:

$$\text{Males: } (\text{kcal} \cdot \text{d}^{-1}) = 66.47 + [13.75 \times \text{weight (kg)}] + [5.00 \times \text{height (cm)}] - (6.76 \times \text{age})$$

$$\text{Females: } (\text{kcal} \cdot \text{d}^{-1}) = 655.10 + [9.56 \times \text{weight (kg)}] + [1.85 \times \text{height (cm)}] - (4.68 \times \text{age})$$

Activity factors of 1.6 and 1.3 were used for ambulatory and bed rest phases, respectively. This was based on findings from previous bed rest studies that basal (resting) energy expenditure does not change during bed rest, but activity-induced expenditure is lower (1–3). Carbohydrate, fat, and protein intakes were to remain at 55, 30, and 15% of calories (except as noted below). The primary goal of dietary support was to maintain constant bodyweight of the subjects, measured daily before breakfast using a bed scale. Dietary intervention to prevent weight loss or gain occurred if a subject's bodyweight deviated by 3% or more from their weight on bed rest day 3 (BR3), at which point the initial fluid shift and any diuresis resulting from postural change should have been completed. When necessary, caloric intake was manipulated by increasing carbohydrates and fat while keeping protein constant.

The target intake of nutrients (**Table I**) was based on the NASA spaceflight nutritional requirements (10), with some adaptations for the ground-based model used here to make a set of bed rest nutrient intake requirements. Calcium and phosphorus intakes were targeted to be about 1400 $\text{mg} \cdot \text{d}^{-1}$. Sodium was targeted to be less than 3500 $\text{mg} \cdot \text{d}^{-1}$ and potassium, 3000–3500 $\text{mg} \cdot \text{d}^{-1}$. Target fluid intake was 28.5 $\text{ml} \cdot \text{kg}^{-1}$ bodyweight. Filtered water was provided for drinking and used in food preparation. For other nutrients, intake was considered acceptable if it met 100–125% of bed rest requirements on average, with daily intake not less than 80% of the requirement.

All menus were composed and actual dietary intakes were determined using the Nutrition Data System for Research (NDS-R) software [Version 5.0_35, May 2004, developed by the Nutrition Coordinating Center (NCC), University of Minnesota, Minneapolis, MN] (14). A sample menu is shown in **Table II**. The NCC Food and Nutrient Database contains values for 136 nutrients, nutrient ratios, and other food components. This database program includes more than 18,000 foods, including many ethnic foods, and 8000 other brand-name products. If an analytic value is not available for a nutrient in a food, the NCC calculates the value based on other nutrients in the same food or on a product ingredient list, or imputes the value based on the nutrient content of similar foods. As a result, database completeness ranges from 97 to 100% of the 136 nutrient components.

Menu Development

The menu contained a variety of fresh, frozen, dried, ready-to-eat, and heat-and-serve foods (Table II). Whenever possible, foods and drinks were chosen that were fortified with vitamins and calcium. Every effort was made to make the food attractive and palatable. The menus were devised to reflect the diversity of cultures and ethnicities of the subjects, who had a variety of taste preferences and food aversions. No food item was served more than once in the same day. Similar foods were not served at the same meal on consecutive days. Menus were rotated on a 7-d cycle for the 60-d subjects and on a 10-d cycle for the 90-d subjects. Menus and schedules were also altered to accommodate study protocols, when necessary.

The initial plan was for all nutrients to be provided from food sources. However, multivitamins were prescribed for the first three subjects. Multivitamin use was discontinued after subject 3; instead, only food items were used to meet nutrient requirements.

Kitchen Activity and Meal Serving Schedules

Menus prepared using NDS-R were converted into menu charts using Microsoft™ Excel. The charts were updated daily to reflect dietary changes and then were forwarded to the dietary staff. The updated charts were placed in each subject's binder. Each menu chart was labeled with the subject's name, date, bed rest day, the meals that were being prepared for the day, and the gram amount of each food item. Any discrepancies in the amount of foods consumed by each subject were recorded at the end of each meal. All foods were weighed to ± 0.1 g using Mettler Toledo (Columbus, OH) scales. Food items were prepared 1 d in advance. Portions were weighed, placed in individual containers, labeled with the subject ID numbers and grams of food, and refrigerated. Serving trays were also labeled with the subject's number and date. To ensure accuracy of measurements, the weights of certain food items were randomly checked throughout the day.

The timing of meal service varied from day to day in accordance with testing schedules. In many cases, meal times were changed because tests were running behind schedule or a test had to be postponed or canceled. On rare occasions when a subject could not or would not consume all required food for a day, intake was recorded accordingly, but unless bodyweight changed, intake was not adjusted.

RESULTS

Nutrient intakes for ambulatory (pre- and post-bed rest) and bed rest phases are shown in Table I. The mean

TABLE I. NUTRIENT INTAKE (MEAN VALUES ± SD) FOR SUBJECTS (N = 13) BEFORE, DURING, AND AFTER BED REST, COMPARED WITH REQUIRED INTAKES.

Nutrient	Mean Intake Pre-Bed Rest	Mean Intake Bed Rest	Mean Intake Post-Bed Rest	Bed Rest Requirement	Acceptable Range for Bed Rest	Spaceflight Requirement	DRI
Energy, kcal	2540 ± 429	2156 ± 340	2388 ± 338	Maintain BW		WHO (moderate activity)	
Fat, g	87 ± 16	75 ± 12	82 ± 11				
Carbohydrate, g	357 ± 58	301 ± 47	336 ± 47				130 g · d^{-1}
Protein, g	96 ± 16	82 ± 15	90 ± 15	12–15% of total energy	12–15% of total energy	12–15% of total energy	56 g · d^{-1} (M) 46 g · d^{-1} (F)
% kcal from fat	31% ± 1%	31% ± 1%	31% ± 1%	30–35% of total energy	30–35% of total energy	30–35% of total energy	20–35% of total energy
% kcal from carbohydrate	56% ± 1%	56% ± 1%	56% ± 1%				45–65% of total energy
% kcal from protein	15% ± 0%	15% ± 1%	15% ± 1%	12–15% of total energy		12–15% of total energy	10–35% of total energy
Vitamin A, μg RE	2217 ± 501	1888 ± 408	1995 ± 560	1000 μg RE	1000-1500 μg RE	1000 μg RE	900 μg RE (M) 700 μg RE (F)
Vitamin D, μg	7.2 ± 1.7	6.4 ± 1.3	8.2 ± 4.0	10 μg (400 IU)	8-12 μg	10 μg (400 IU)	5 μg (200 IU)
Vitamin E, mg α-TE	15.5 ± 3.5	12.9 ± 2.9	12.5 ± 4.6	20 mg α-TE	20 mg α-TE	20 mg α-TE	15 mg α-TE
Vitamin K, μg	125 ± 24	109 ± 19	101 ± 50	80 μg (M) 65 μg (F)		80 μg (M) 65 μg (F)	120 μg (M) 90 μg (F)
Vitamin C, mg	211 ± 60	204 ± 33	166 ± 60	100 mg		100 mg	90 mg (M) 75 mg (F)
Thiamin, mg	2.2 ± 0.4	1.9 ± 0.4	2.0 ± 0.5	1.5 mg		1.5 mg	1.2 mg (M) 1.1 mg (F)
Riboflavin, mg	2.5 ± 0.4	2.1 ± 0.4	2.3 ± 0.4	2.0 mg		2.0 mg	1.3 mg (M) 1.1 mg (F)
Niacin, mg	29.1 ± 5.1	25.1 ± 4.5	29.2 ± 6.1	20 mg		20 mg	16 mg (M) 14 mg (F)
Pantothenic acid, mg	6.4 ± 1.4	5.5 ± 1.1	5.5 ± 1.4	5.0 mg		5.0 mg	5.0 mg
Vitamin B6, mg	2.9 ± 0.5	2.4 ± 0.4	3.0 ± 0.9	2.0 mg		2.0 mg	1.3 mg
Folate, μg	582 ± 96	475 ± 74	599 ± 143	400 μg		400 μg	400 μg
Vitamin B12, μg	7.5 ± 1.5	5.9 ± 1.2	8.1 ± 3.0	2.0 μg		2.0 μg	2.4 μg
Calcium, mg	1352 ± 246	1154 ± 183	1147 ± 298	1000–1200 mg	900–1200 mg	1000–1200 mg	1000 mg
Phosphorus, mg	1650 ± 257	1370 ± 251	1516 ± 281	1000–1200 mg	900–1200 mg	1000–1200 mg	700 mg
Magnesium, mg	370 ± 72	315 ± 69	340 ± 72	350 mg (M) 280 mg (F)		350 mg (M) 280 mg (F)	420 mg (M) 320 mg (F)
Iron, mg	18.7 ± 3.1	16.0 ± 2.6	16.5 ± 4.1	10 mg (M) 18 mg (F)	10–20 mg	10 mg	8 mg (M) 18 mg (F)
Zinc, mg	14.2 ± 2.7	11.6 ± 2.1	12.9 ± 2.6	15 mg		15 mg	11 mg (M) 8 mg (F)
Copper, mg	1.67 ± 0.40	1.42 ± 0.34	1.49 ± 0.37	1.5–3.0 mg	1.5–3.0 mg	1.5–3.0 mg	0.9 mg
Selenium, μg	145 ± 25	126 ± 26	136 ± 25	70 μg		70 μg	55 μg
Sodium, mg	3554 ± 730	2997 ± 594	2938 ± 1000	< 3500 mg	< 3500 mg	< 3500 mg	1500 mg
Potassium, mg	3358 ± 607	2791 ± 488	2823 ± 621	3500 mg	3000–3500 mg	3500 mg	4700 mg
Fluid, ml	4095 ± 810	3811 ± 607	3836 ± 679	28.5 ml per kg	2–4 L	1.0–1.5 ml per kcal	3.7 L · d^{-1} (M) 2.7 L · d^{-1} (F)
Fiber, g	24.5 ± 4.4	21.1 ± 4.4	22.8 ± 5.0	10-25 g	10–25 g	10–25 g	38 mg (M) 25 mg (F)
Manganese, mg	4.7 ± 0.8	4.1 ± 0.8	4.8 ± 1.0	2.0-5.0 mg		2.0–5.0 mg	2.3 mg (M) 1.8 mg (F)

DRI = dietary reference intake; BW = bodyweight; WHO = World Health Organization; M = males; F = females; RE = retinol equivalent; TE = tocopherol equivalent. DRI values provided are for 31- to 50-yr-old men and women (combined when the same) (5–9).

TABLE II. SAMPLE MENU FOR ONE MENU CYCLE OF 6 DAYS, THREE MEALS PER DAY.

	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7
B	waffle	English muffin	oatmeal	cinnamon French toast	bagel	scrambled egg	cereal
	syrup	sausage/egg	apple	grape jelly	cream cheese	strawberries	milk
	pork sausage	OJ/milk	butter	butter	milk/OJ	sausage	fruit plate
	egg	fruit	salt	strawberries	bacon	muffins	nuts
	fruit		OJ/milk	OJ/milk	fruit	OJ/milk	OJ/milk
	OJ/whole milk				OJ/milk		
L	**TUNA CASSEROLE**	**SPAGHETTI**	**CHICKEN AND EGG SALAD**	**CHEESEBURGER**	**PIZZA**	**CHICKEN BEAN ENCHILADA**	**HAMBURGER**
	tuna	spaghetti	chicken breast	whole wheat hamburger bun	pepperoni French bread pizza	tortilla	ground beef
	mayonnaise	sauce	pita	butter	mixed veggies	black beans	wheat bun
	macaroni noodles	ground beef	poultry seasoning	sloppy joe mixture	ground pepper	chicken	tomato slice
	butter	black pepper	egg salad	ground beef	lettuce	mozzarella cheese	lettuce
	pita bread	broccoli	dinner roll	cheese	tomato	yellow corn	ranch
	ranch dressing	mozzarella cheese	lettuce	potato salad	Italian dressing	salsa	corn
	pita bread	drink	tomato	apple juice	vanilla crème cookies	sour cream	butter
	drink		mandarin orange		orange	apple pie	mustard
			apple pie		drink	poultry seasoning	ketchup
			drink			butter	drink
						drink	
D	**PORK CHOP**	**HONEY CHICKEN**	**BBQ**	**CHICKEN & RICE**	**BAKED FISH**	**LASAGNA**	**SALMON CAKE**
	pork chop	honey chicken	BBQ beef brisket	chicken and mushrooms	tilapia filet	lasagna with meat	salmon cake
	baked potato	honey mustard	mac and cheese	ground pepper	couscous	French bread	canola oil
	green beans	broccoli rice casserole	green beans	brown rice	sugar snap peas	butter	wild rice
	apple	carrots	dinner roll	carrots	broccoli	garlic	butter
	peas and carrots	dinner roll	butter	broccoli	ice cream	drink	ketchup
	vegetable juice blend	drink	mixed veggies	green beans	drink		carrots
	BBQ sauce		drink	dinner roll			black pepper
	butter			butter			drink
	mozzarella cheese			drink			
	drink						

B = breakfast; L = lunch; D = dinner.
Drink options were lemonade and other fruit-flavored drinks; OJ = orange juice.

(± SD) intake for subjects at bed rest was 2156 ± 340 calories, with an average ratio of carbohydrates/protein/fat of 56/15/31% of the total. Subjects consumed 98 ± 2% of their predicted energy intake before bed rest, 103 ± 4% of predicted intake during bed rest, and 93 ± 8% of predicted intake after bed rest.

Of the fat-soluble vitamins, the intakes of vitamins D and E were below required values for both ambulatory and bed rest phases. Data reflect dietary intake only (and do not include the multivitamin provided to the first three subjects). Bodyweight of the subjects, measured daily before breakfast, is shown in **Fig. 1**. Mean data are presented for each group of subjects.

DISCUSSION

Diet and nutrition are critical elements of bed rest studies, and as with all elements of research design, there are many options for what elements of diet to control and how to control them. Some examples: provide calories and maintain body mass at pre-bed rest levels, or allow subjects to lose weight, as often (but not always) happens during spaceflight; what degree of food selection to allow subjects, including quantity and quality (such as choice of protein sources); use of vitamin, mineral, fiber, or other supplements; and even source and timing of food procurement. The options selected have an impact on the logistics and effort required to provide food for research studies, and can affect the interpretation of findings, both within and between studies. Determining the optimal balance between cost, logistics, subject compliance and retention, and scientific impact is often not easy, and optimal balance may shift over the course of the study.

The challenges of maintaining bodyweight and providing 100% of nutrient requirements required constant monitoring and adjustment. The challenges included adjustments for weight changes, menu fatigue, food allergies and intolerances, difficulties providing all micronutrients within the smaller portions for smaller individuals, and adjustment of caloric intake in the transition from ambulatory to bed rest conditions. Some researchers (11,12) have thought it essential to order same-lot food items to eliminate concerns about changes in nutrient intake and food availability throughout the duration of long-term or crossover-design studies. In the present study, many prepackaged food items were used, which reduced variability in nutrient content.

Achieving the bed rest requirements for vitamin D and calcium was a challenge throughout the study. Calcium is found in a greater variety of foods than is vitamin D, and the major dietary sources of vitamin D are

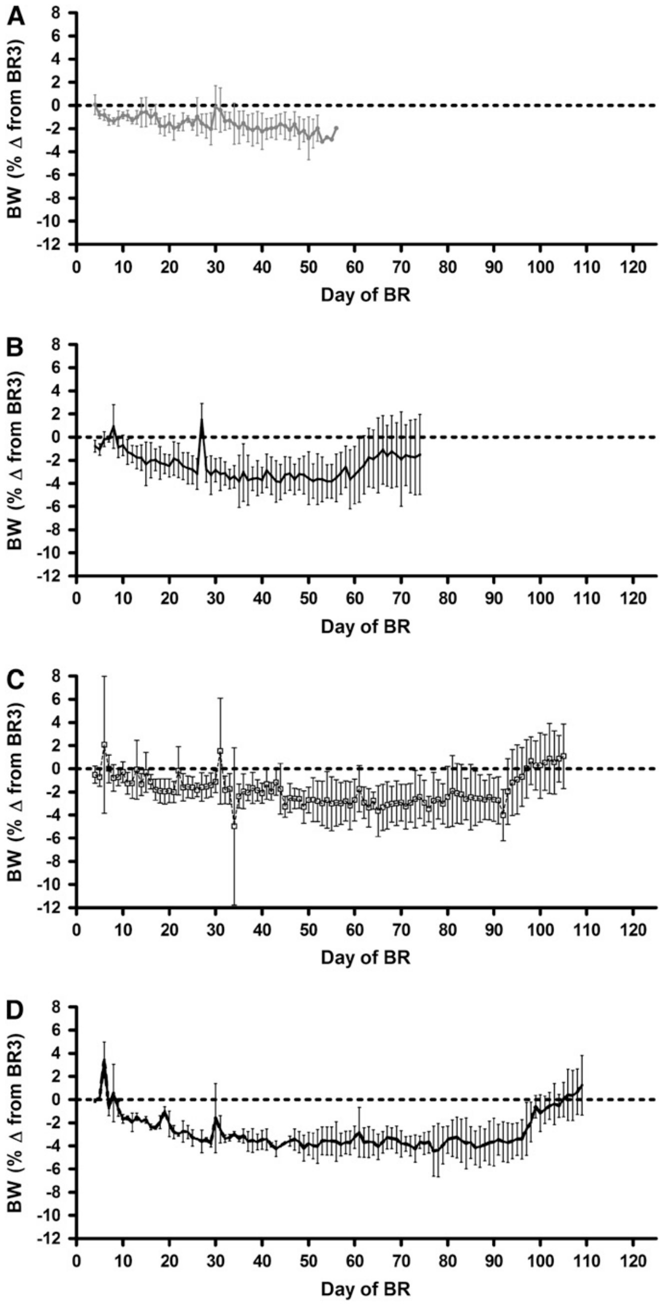

Fig. 1. Daily bodyweight (BW) of subjects by group during bed rest (mean ± SD). Data are expressed as percent change from the individual's bodyweight on day 3 of bed rest (BR3). A) $N = 4$ subjects, 42, 44, 49, or 52 d of head-down bed rest; B) $N = 3$, 60 d of head-down bed rest; C) $N = 4$, 90 d of head-down bed rest; D) $N = 2$, 90 d of head-down bed rest.

fortified foods. Great care was taken to include foods that were fortified with vitamin D or calcium, or both. Despite the addition of these foods, in most instances, vitamin D intake was still below bed rest requirements.

A related issue concerns the use of multivitamins during bed rest studies. Multivitamins were prescribed to subjects 1-3, but multivitamin use was discontinued after subject 3; instead, only food items were used to meet nutrient requirements. Although it may be possible to meet the vitamin D requirements in bed rest, the difficulties in accomplishing this goal in bed rest and during flight highlight the issue of balancing priorities between presentation, variety, and palatability of the meals, and meeting nutrient requirements.

Other nutrient requirements were also not provided by the food, specifically vitamin E, and to a lesser extent (that is, these were closer to the requirement), zinc and magnesium. Circulating levels of alpha-tocopherol did not change in these subjects (15). Serum zinc, one of several imperfect markers of zinc status, was unchanged. Urinary magnesium declined at the end of bed rest, but did not correlate with dietary magnesium (15). The intake and status of these nutrients bring to light the difficulty in implementing a controlled diet with a detailed set of requirements. Fitting all of the pieces of the puzzle together is difficult, if not impossible.

As has been described in this paper, diet and nutrition are critical elements of bed rest studies. Both of these elements have many facets, and a great deal of attention must be paid to the details. Standardized and controlled dietary conditions are critical for experiment success.

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