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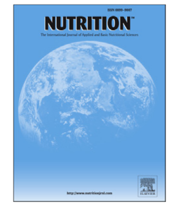

Basic nutritional investigation

New compartment model analysis of lean-mass and fat-mass growth with overfeeding

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ABSTRACT

Objectives: Mathematical models of lean- and fat-mass growth with diet are useful to help describe and potentially predict the fat- and lean-mass change with different diets as a function of consumed protein and fat calories. Most of the existing models do not explicitly account for interdependence of fat-mass on the lean-mass and vice versa. The aim of this study was to develop a new compartmental model to describe the growth of lean and fat mass depending on the input of dietary protein and fat, and accounting for the interdependence of adipose tissue and muscle growth.

Methods: The model was fitted to existing clinical data of an overfeeding trial for 23 participants (with a high-protein diet, a normal-protein diet, and a low-protein diet) and compared with the existing Forbes model.

Results: Qualitatively and quantitatively, the compartment model data fit was smoother with less overall error than the Forbes model. The root means square error were 0.39, 0.93 and 0.72 kg for the new model, the Forbes model, and the modified Forbes model, respectively. Additionally, for the present model, the differences between some of the coefficients (on the cross dependence of fat and lean mass as well as on the intake diet dependence) across different diets were statistically significant ($P < 0.05$).

Conclusions: Our new Dey-model showed excellent fit to overfeeding data for 23 normal participants with some significant differences of model coefficients across diets, enabling further studies of the model coefficients for larger groups of participants with obesity or other diseases.

Introduction

The high prevalence of overweight in the population has become increasingly important because overweight and obese individuals are susceptible to a number of diseases such as hypertension, diabetes, heart disease, and cancer [1,2]. Up to 69% of adults can be categorized as overweight; of these 35.1% are obese [3]. A properly organized diet can help to maintain a healthy weight and improve quality of life. To our knowledge, the significance of diet composition in response to overeating and energy dissipation in humans has not been well studied [4]. The effect of dietary protein on weight gain [5] was recently investigated in a controlled clinical study [6]. Overeating produced significantly less weight gain in individuals consuming a low-protein diet (LPD) than in individuals consuming a normal (NPD) or a high-protein diet (HPD).

This study is significant because the average daily diet for an individual is rarely balanced. Different foods and meals obviously contain different amounts of calories due to the various compositions of nutrients (fat, protein, carbohydrate). A mathematical model can be useful to generalize the results of the clinical trial and help to predict the effect of a particular

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diet on weight gain. The model can be important for certain cases where weight gain depends on diet only, without exercising. Also, existing models [6] that describe dependence of changes in the fat-free mass on the changes in fat mass do not explicitly take into account the interdependence of each of these independent energy reservoirs. We developed a compartment model with differential equations defining the change in lean and fat mass and their mutual dependence. In the present model, we consider the effect of dietary protein and fat consumption on lean- and fat-mass growth. The coefficients for the different terms of differential equation can be interpreted as a guide to which effects are stronger or weaker. We compared the present model performance on clinical data with that of the Forbes [6,7] model.

Background clinical study

The clinical study we are interested in was described previously [4]. Briefly, this was an overfeeding experiment conducted with 25 healthy, weight-stable individuals aged 18 to 35 y. Body mass index was between 19 and 30 kg/m^2. Three important characteristics of the protocol were measured frequently, which allows for modeling: body composition, resting energy expenditure, and total energy expenditure. Body composition was measured by dual x-ray absorptiometry and resting energy expenditure was measured by ventilated hood every 2 wk. Total energy expenditure was measured by double-labeled water before overeating, during a weight stabilization period and during the last week of the overfeeding paradigm.

Diet

After a weight stabilization period (13–25 d) at baseline, participants were randomly distributed to consume a diet that contained 5%, 15%, or 25% protein. Protein contribution to the diet defined LPD (5%), NPD (15%), and HPD (25%). Participants were overfed with the assigned diets for 8 wks. The metabolic kitchen prepared diets that were provided to participants in 5-d rotation with overfeeding calories prescribed in proportion to run-in energy requirement. A 5-d diet for each participant was prepared in duplicate, frozen, and prepared for the Covance Laboratories for protein, fat, and carbohydrate content analysis. Carbohydrate concentration was constant throughout the study. The chemical analysis showed that the LPD had 6% of energy from protein, 52% from fat, and 42% from carbohydrates. NPD had 15% of energy from protein, 44% from fat, and 41% from carbohydrates. HPD had 26% of energy from protein, 33% from fat, and 41% from carbohydrates.

Participants lived on the metabolic ward from the run-in period, through baseline testing and for the entire overfeeding period.

Number of participants

In all, there were 25 participants; 8 in each of the HPD and LPD groups and 9 in the NPD group. However, measured weight data were missing for one participant in the LPD group and one in the NPD group; hence they were eliminated from analysis.

Background on existing mathematical model

Different existing models explore the dependence of energy expenditure and fat mass [5]. The Hall model consists of two differential equations that describe dependence of the body composition change depending on the energy expenditure and storage of glycogen.

$$\rho_F \frac{dF}{dt} = (1-p)\left(EI - EE - \rho_G \frac{dG}{dt}\right) \tag{1}$$

$$\rho_L \frac{dL}{dt} = p\left(EI - EE - \rho_G \frac{dG}{dt}\right) \tag{2}$$

In formulas 1 and 2 ρ_L, ρ_F represent the energy content per unit change of body lean and fat masses, ρ_G represents the energy density of glycogen, *EI* is energy intake and *EE* is energy expenditure, *G* is the glycogen intake, *p* is partitioning function (detailed description in the original paper [5]).

However, the present experimental data from the overfeeding study [4] does not have the information about the amount of energy expenditure and change in glycogen.

The Forbes model [6,7] was introduced as a model for predicting individual weight change in humans.

$$FFM(t) = 10.4 \ln\left(\frac{F(t)}{D}\right) \tag{3}$$

FFM is fat-free mass and F is a fat mass. We used the Forbes model to compare to our model predictions. Fat mass was

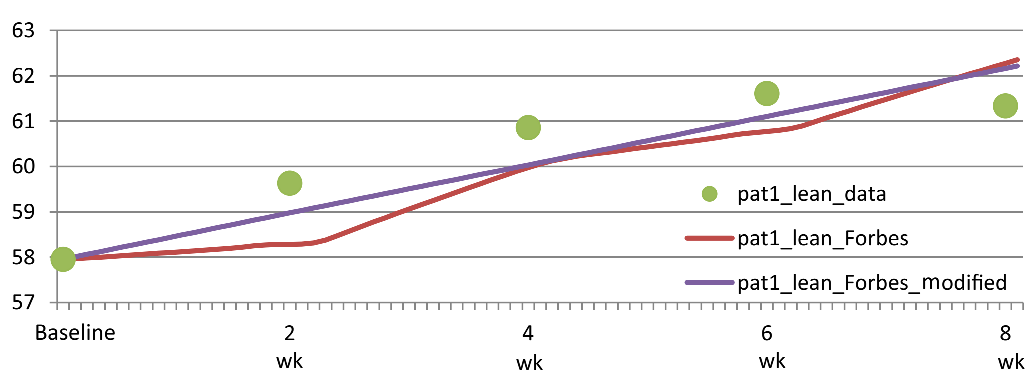

Fig. 1. Lean mass of participant 1 change with a high-protein diet, fitted to Forbes and modified Forbes models.