HIGHER ENERGY INTAKE VARIABILITY AS PREDISPOSITION TO OBESITY: NOVEL APPROACH USING INTERQUARTILE RANGE

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SUMMARY

Objective: It is known that total energy intake and its distribution during the day influences human anthropometric characteristics. However, possible association between variability in total energy intake and obesity has thus far remained unexamined. This study was designed to establish the influence of energy intake variability of each daily meal on the anthropometric characteristics of obesity.

Methods: A total of 521 individuals of Czech Caucasian origin aged 16–73 years (390 women and 131 men) were included in the study, 7-day food records were completed by all study subjects and selected anthropometric characteristics were measured. The interquartile range (IQR) of energy intake was assessed individually for each meal of the day (as a marker of energy intake variability) and subsequently correlated with body mass index (BMI), body fat percentage (%BF), waist-hip ratio (WHR), and waist circumference (cW).

Results: Four distinct models were created using multiple logistic regression analysis and backward stepwise logistic regression. The most precise results, based on the area under the curve (AUC), were observed in case of the %BF model (AUC = 0.895) and cW model (AUC = 0.839). According to the %BF model, age ($p < 0.001$) and IQR-lunch ($p < 0.05$) seem to play an important prediction role for obesity. Likewise, according to the cW model, age ($p < 0.001$), IQR-breakfast ($p < 0.05$) and IQR-dinner ($p < 0.05$) predispose patients to the development of obesity. The results of our study show that higher variability in the energy intake of key daily meals may increase the likelihood of obesity development.

Conclusions: Based on the obtained results, it is necessary to emphasize the regularity in meals intake for maintaining proper body composition.

Key words: anthropometry, energy distribution, energy intake, obesity, interquartile range, variability

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INTRODUCTION

An enormous increase in the number of obese patients, i. e. patients with body mass index (BMI) ≥ 30 kg/m^2, has taken place during the past three decades. Along with the increasing prevalence of type 2 diabetes mellitus, this situation has contributed to the development of a new 21st century pandemic (1, 2). Obesity is caused by excessive fat accumulation caused in turn by increased energy intake, inappropriate eating patterns (e.g. irregular food intake), low energy expenditure, and genetic factors.

In the past several years, issues such as food composition, eating regularity, energy intake and changes in metabolism and body weight have become of significant research interest (3–5), especially as it has been shown that irregular food intake is linked to an increase in body weight (6).

The results of various studies indicate that eating less than 3 to 4 meals per day may lead to an increase in BMI (7), adiposity (8) and central obesity (9), and may negatively affect appetite control (10). Skipping one or more of the main daily meals (especially breakfast) is associated with obesity development and such a course cannot be recommended as a weight management technique (6). On the other hand, eating five or more meals per day is associated with a lower BMI and waist-hip ratio (WHR) and seems to be an important factor in weight loss maintenance (11). An additional theoretical model focusing on the relationship between eating frequency and appetite regulation (12) is based on studies associating eating frequency (ranging from 3 to 6 meals per day) with successful appetite regulation.

With respect to both the number of meals and to energy density (ED), a study by De Castro established that low ED intake in adults during any main daily meal may reduce overall food intake since the higher the ED of a particular ingested food, the more this food is eaten (13). Morning food intake is particularly satiating and may help reduce the total amount of food ingested during the day; on the other hand, eating late at night lacks the necessary satiating value and may result in greater overall daily intake (13). Taken together, the results of the above mentioned studies employing various methods in order to assess the regularity of food intake and its energy content are contradictory. Moreover, none of the studies focused on food intake regularity and energy content simultaneously. The aim of this study was therefore to establish the energy content of each daily meal and, with the help of 7-day food records, assess its variability during the course of one week. Interquartile range (IQR) was employed as it reflects the variability in food intake better than standard deviation, which can be easily skewed by one extreme value. IQR makes it possible to study food intake regularity, the number and size of portions and, to a certain degree, also the sequence of meals eaten throughout the day.

MATERIALS AND METHODS

Subjects

A total of 521 participants, 390 women and 131 men of Czech Caucasian origin (BMI 32.62 ± 7.86 kg/m^2) aged 16–73 (45.41 ± 13.25 years) were included in the study. All study participants were recruited in a mass media campaign targeting the population of the South Moravia Region in the Czech Republic (14). The study was conducted according to guidelines set out in the Declaration of Helsinki and all procedures involving human subjects were approved by the Committee for Ethics of Medical Experiments on Human Subjects, Faculty of Medicine of Masaryk University (Brno, Czech Republic). Written informed consent was obtained from all subjects and subsequently archived.

Anthropometric Characteristics

All anthropometric measurements were carried out by three specialists and included weight, height, BMI, body fat percentage (%BF), body water percentage (%BW), waist circumference (cW), hip circumference (cH), and waist-hip ratio (WHR). For weight, height and BMI measurements, carried out using a precisely calibrated SECA 764 scale (Medical Measuring System, Hamburg, Germany), subjects were required to wear light indoor clothes and no shoes. cW and cH were measured with an accuracy of 0.5 cm. cW was measured at umbilicus level. Body composition was assessed by bioelectrical impedance analysis using a Bodystat 1500 single frequency bio-impedance analyser (Bodystat Ltd., Isle of Man, UK) with the subject lying in a supine position.

In order to eliminate distortion of body composition measurements due to differences in hydration between study participants, all study subjects were strictly instructed on how to maintain proper hydration status in accordance with the Bodystat 1500 Hardware User's Guide. All subjects suffering from fever, acute inflammatory disease, lymphoedema or patients after transplant were excluded (15). Anthropometric measurements were completed in the morning on an empty stomach, following morning bowel movements and prior to any consumption of fluids or exercise.

Dietary Intake

All participants completed 7-day food records. In order to eliminate the effect of night shift work, subjects working at night were not included. Food intake data collected from study subjects were submitted to further analysis. Daily energy intake from all macronutrients and energy intake broken down by specific times of a day (i.e. breakfast, mid-morning snack, lunch, afternoon snack, dinner and supper) was calculated using Nutrimaster Diet Analysis software modified for the Czech population (Abbott Laboratories, Abbott Park, IL, USA). The same method was recently used in another study conducted by this research group.(16)

Special attention was paid to meal regularity and energy content, subsequently evaluated as interquartile range. IQRs reflecting the variability of energy content of each daily meal (breakfast, mid-morning snack, lunch, afternoon snack, dinner and supper) were established. For example, the following may be said regarding the energy content of all breakfasts eaten during the week: low IQR was calculated in case energy content was consistent, i.e. in case of subjects eating the same breakfast every morning, while high IQR was established in case of irregular food intake, e.g. skipping breakfast (breakfast energy content is zero) or eating large portions on some days and small portions on other days. In a subsequent analysis, the IQR of single daily meals was examined in order to establish whether or not it affects anthropometric characteristics such as BMI, %BF, cW and WHR, and whether this variability in food intake predisposes subjects to obesity.

Statistical Analysis

Multiple logistic regression analysis was used to identify risk factors associated with the occurrence of obesity. IQR was calculated as the difference between upper and lower energy intake quartiles from single daily meals and subsequently implemented as a parameter of variability. Four models designed to examine the effect of daily meal IQR (independent variables) on anthropometric characteristics (dependent variables) were established: BMI model, %BF model, cW model, and WHR model. Logistic regression modelling was adjusted for age and gender as independent variables. A backward stepwise procedure was used to evaluate variables significantly associated with the outcome. The selection of candidate risk factors may be viewed as the problem of selecting variables in predictive models. Stepwise selection of variables is a conditionally univariate approach based on the inclusion (or exclusion) of a single variable at a time, conditioned on the variables already included. Given a starting model containing all variables and the intercept, the method repeatedly adds or deletes single variables according to a designated addition or deletion criterion. If no variables meet either criterion, the process is terminated. In case of this study, the Akaike Information Criterion (AIC) was used to determine inclusion and exclusion.

Receiver operating characteristic (ROC) curves were produced by the logistic regression model and compared with the area under the receiver operating characteristic curves (AUC) from different models (17).

Data were analyzed using R open-source software for statistical computing (Version 2.12.0)*. Results exhibiting a p value < 0.05 were considered statistically significant.

*http://www.r-project.org/

Table 1. Anthropometric parameters of study subjects

Variable	Females (n=390)			Males (n=131)			All subjects (n=521)		
	Mean	SD	Median	Mean	SD	Median	Mean	SD	Median
Age (years)	45.66	13.23	47.20	44.69	13.32	44.20	45.41	13.25	46.80
BMI (kg/m^2)	32.46	8.08	31.80	33.10	7.16	32.20	32.62	7.86	31.90
%BF	40.17	9.82	41.15	28.33	8.50	28.00	37.19	10.80	38.10
%BW	44.86	6.30	44.30	51.86	6.22	52.20	46.62	6.97	46.30
cW (cm)	98.30	18.15	98.00	110.81	18.50	110.00	101.44	19.01	101.00
WHR	0.85	0.08	0.85	0.98	0.09	1.01	0.88	0.10	0.88

BMI – body mass index, %BF – percentage of body fat, %BW – percentage of body water, cW – waist circumference, WHR – waist-hip ratio

RESULTS

Basic demographic and anthropometric data including age, BMI, %BF, %BW, cW, and WHR for all subjects, listed by sex, are presented in Table 1.

BMI Model

An obesity model including BMI (dependent variable) and sex in association with all daily meal IQRs (independent variables) was created using logistic regression modelling. After stepwise backward elimination based on AIC, only the following variables seem to play an important obesity prediction role: age ($\beta=0.07230$, $p<0.001$), male sex ($\beta=1.01970$, $p=0.018$), IQR-breakfast ($\beta=0.00030$, $p=0.053$), IQR-dinner in females ($\beta=0.00050$, $p=0.004$), and IQR-dinner in males ($\beta=-0.00070$, $p=0.018$).

Age was found to be the most important obesity prediction variable. Furthermore, a significant association between sex and IQR-dinner results in positive β IQR-dinner in women and negative β IQR-dinner in men was found. This means that a higher IQR-dinner value increases the likelihood of obesity in women (according to BMI) while decreasing it in men. The accuracy of the reduced BMI model measured by means of AUC is 0.753.

%BF model

An obesity model including %BF (dependent variable) and sex in association with all daily meal IQRs (independent variables) was created using logistic regression modelling. After stepwise backward elimination based on AIC, only the following variables seem to play an important obesity prediction role: age ($\beta=0.16100$, $p<0.001$), IQR-lunch ($\beta=0.00050$, $p=0.039$) and IQR-afternoon snack ($\beta=-0.00040$, $p=0.072$). This means that the higher the age and IQR-lunch, the higher the probability of being classified as obese according to %BF. On the other hand, increasing the value of IQR-afternoon snack diminishes the probability of being classified as obese (according to %BF). The accuracy of the reduced %BF model measured by means of AUC is 0.897.

cW Model

An obesity model including cW (dependent variable) and sex in association with all daily meal IQRs (independent variables) was created using logistic regression modelling. After stepwise backward elimination based on AIC, only the following variables seem to play an important obesity prediction role: age ($\beta=0.11140$, $p<0.001$), IQR-breakfast ($\beta=0.00050$, $p=0.036$),

Table 2. Relationship between interquartile range (IQRs) of selected daily meals and anthropometry of subjects

Variable	Parameter	Sex	β	p-value
Body mass index	Age	f, m	0.07230	<0.001
	IQR breakfast	f, m	0.00038	0.053
	IQR dinner	f	0.00057	0.004
	IQR dinner	m	−0.00074	0.018
Percentage of body fat	Age	f, m	0.16100	<0.001
	IQR lunch	f, m	0.00059	0.039
	IQR snack afternoon	f, m	−0.00044	0.072
Waist circumference	age	f, m	0.11140	<0.001
	IQR breakfast	f, m	0.00059	0.036
	IQR snack-forenoon	f, m	−0.00067	0.004
	IQR dinner	f, m	0.00045	0.025
Waist-hip ratio	Age	f, m	0.08290	<0.001
	IQR breakfast	f, m	0.00031	0.083
	IQR supper	f, m	0.00032	0.016

IQR-mid-morning snack, (β=−0.00060, p=0.004), IQR-dinner (β=0.00040, p=0.025). This means that the higher the age, IQR-breakfast and IQR-dinner, the higher the probability of being classified as obese according to cW. On the other hand, increasing the value of IQR-mid-morning snack diminishes the probability of being classified as obese according to cW. The accuracy of the reduced cW model measured by means of AUC is 0.805.

WHR model

An obesity model including WHR (dependent variable) and sex in association with all daily meal IQRs (independent variables) was created using logistic regression modelling. After stepwise backward elimination based on AIC, only the following variables seem to play an important obesity prediction role: age (β=0.08290, $p<0.001$), IQR-breakfast (β=0.00030, p=0.083), IQR-supper (β=0.00030, p=0.002). This means that the higher the age and IQR-breakfast and IQR-supper, the higher the probability of being classified as obese according to WHR. The accuracy of the reduced WHR model measured by means of AUC is 0.759.

ROC curves and AUCs for all studied models are shown in Figure 1. Relationships between daily meal IQRs and anthropometric characteristics are shown in Table 2.

DISCUSSION

Our study included a total of 521 volunteers from the South Moravian Region of the Czech Republic. The majority of the study cohort was composed of women, who are generally known to be more concerned with their own body weight and appearance as well as with family health. They also tend to be more aware and active than men in this respect. The authors are aware of the resulting gender-dependent bias of the obtained results.

All models employed in this study showed age as a very strong predictor of obesity. This finding may be explained in several ways. Increasing age may lower the value of basal metabolic rate due to changes in fat free mass (18) or due to illness, disease or other metabolic disorders, as seen in the elderly (19).

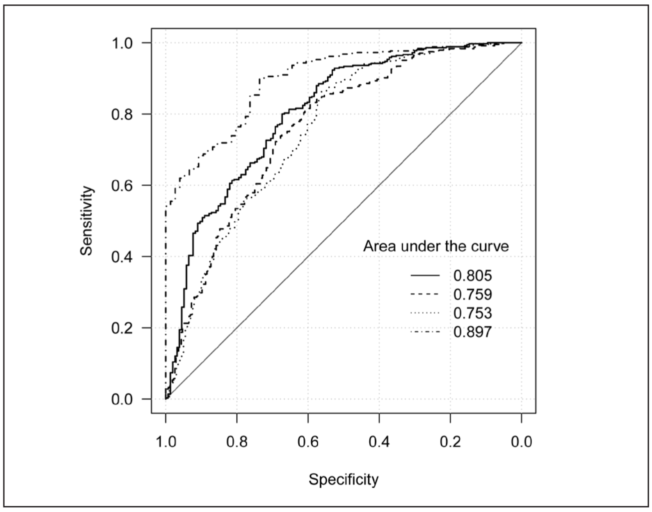

Fig. 1. *Receiver operating characteristic (ROC) curves and areas under ROC curve (AUC) for all models.*

The highest AUC was observed for %BF model, followed by cW, WHR and BMI models.
%BF – percentage of body fat, cW – waist circumference, WHR – waist-hip ratio, BMI – body mass index, AUC – area under the curve

As very little attention has been paid to food intake regularity thus far, this study also focused on relationships between the energy content variability of a particular daily meal and anthropometric parameters found in the study cohort. The studied anthropometric parameters (%BF, cW, BMI and WHR) were selected according to the importance of their role and current use in both research and clinical practice as the most common markers of obesity and fat distribution. Other parameters (e.g. %BW) were not studied any further due to their association with body muscle rather than body fat content.

The study results clearly indicate that there is a statistically significant relationship between the IQR of some daily meals and the anthropometric characteristics of study participants. A comparison of the AUC of all models suggests that the %BF model is the most accurate (AUC=0.897), thereby indicating that %BF may be affected by higher age ($p<0.001$) in connection with higher fluctuations in energy intake at lunch ($p<0.05$). The cW model was evaluated as the second most accurate, indicating that an increase in age ($p<0.001$) and irregular consumption of breakfast ($p<0.05$) and dinner ($p<0.05$) during the week may result in an increase in waist circumference.

The BMI model was evaluated as being least accurate (AUC = 0.753); however, unlike in case of the remaining models, gender was not used as a significant independent variable. Although BMI is a traditionally used anthropometric indicator for the classification of obesity, it does not take into account gender or body composition, which can be very misleading and inaccurate in the assessment of nutritional status in various subpopulations.

The WHR model may be viewed in a similar way since WHR cut-off values are different for men a women. Body circumference values may be affected by a various distribution of muscle and body fat mass. In comparison with cW, cH does not provide any additional information and the fact that WHR is not a suitable parameter for body fat estimation has been established by Suchanek et al. (20) Using cW instead of WHR for assessing obesity and abdominal fat as critical health risk factors is also recommended also by the National Heart, Lung, and Blood Institute. The fact that WHR is not a good indicator of obesity may also be documented using the following example: during the process of reducing body weight and improving body composition, the WHR value may rise due to an increase in muscle mass and simultaneous slight decrease in body fat mass (trunk, hips). On the other hand, WHR is a better predictor of cardiovascular mortality (21) and chronic kidney disease (22).

In view of all of the above mentioned facts, WHR and BMI appear to be less accurate anthropometric obesity indicators than cW or %BF; this correlates with the results of our research.

Most daily energy intake should be consumed at lunch, followed by breakfast and dinner. If this does not happen, an increase in energy intake in the afternoon, evening and at night is observed; this scenario is directly associated with overweight and obesity (23). Similar effects were previously observed in studies by De Castro (13) and Kant et al. (24). For example, Kant et al. state that skipping breakfast results in a tendency to increase the ED of food consumed in the following 24 hours (24). This finding corroborates the results of this study, namely those which indicate that IQR-breakfast ($p<0.05$) is a predictor of obesity as observed in the cW model. The importance and indispensability of breakfast was further shown in other important studies (6, 21, 25).

The results of this study also show that regular breakfast, lunch and dinner times are necessary for maintaining proper body composition. Moreover, it is critical to ensure that the same amount of energy is consumed in individual meals not only during one seven-day period, but also longitudinally. Chronic desynchronization of the circadian system, including energy balance, meal frequency and eating patterns, influences weight regulation in humans (26). Irregular meal frequencies lead to lower postprandial energy expenditures and both of these factors may in turn induce weight gain in the long term (4). On the other hand, regular eating has beneficial effects on fasting lipids, postprandial insulin profiles and thermogenesis (3, 5).

This study shows that in addition to focusing on the composition of a meal, it is also necessary to take into account meal regularity and dietary energy density. Nevertheless, more extensive studies focusing on larger, more gender-balanced populations are needed in order to confirm the results.

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Conflict of Interests

None declared

Authors Contribution

M. Forejt: formulated the research question, designed the study, carried out the study, analysed the data, wrote the manuscript; J. Bienertová-Vašků: formulated the research question, designed the study, analysed the data, wrote the manuscript, critically revised the manuscript; J. Novák: carried out the study, analysed the data, wrote the manuscript; F. Zlámal: analysed the data; wrote the manuscript; M. Forbelská: designed the study, carried out the study, analysed the data; P. Bienert: designed the study, analysed the data; P. Mořkovská and N. Salah: carried out the study, wrote the manuscript; M. Zavřelová and A. Pohořalá: designed the study, carried out the study; M. Jurášková: carried out the study; Z. Derflerová Brázdová: formulated the research question, designed the study, critically revised the manuscript.

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