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Food Energy Density and Body Weight

A scientific statement from the DGE

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Summary

Bearing in mind the high prevalence of overweight in the population, it would be very interesting to identify the factors that influence increases in weight, or successful weight loss or weight maintenance. Numerous studies have shown that food energy density is one of these factors. The German Nutrition Society (DGE) introduces the concept of energy density. Together with nutritional density, this is a useful concept in the evaluation of foods – apart from drinks. Current scientific findings suggest that there is a positive association between food energy density and body weight. A nutritional pattern with low energy density can help to maintain or reduce body weight. The DGE concludes that measures to control weight should consider food energy density.

Keywords: energy density, body weight, overweight, obesity, weight loss

Introduction and objective

Changes in the living conditions in Germany have led to a marked decrease in physical activity. However, nutrition has not been adapted to the resulting decrease in energy requirements. In parallel to these changes in lifestyle and working environment, there has been a fundamental change in nutritional behaviour and food culture. These diverse changes are described in the nutritional reports of the German Nutrition Society (DGE); they have been very rapid and have taken place within only a few generations. A wide variety of relatively cheap and tasty foods are now available – everywhere and at any time. Many of these are of high energy density. It is becoming increasingly difficult to achieve a long-term energy balance – particularly for consumers with inadequate knowledge of the composition and preparation of foods [1].

This has lead to a high prevalence of overweight in the population. This frequently starts in children and adolescents and is particularly marked in socially disadvantaged families. The increase in weight continues in adults and is affecting more and more people. As a consequence, people of normal weight in Germany are in a minority from the age group of 30 to 34 (men) or 55 to 59 (women). 67 % of men and 53 % of women are overweight. At the same time, increasing numbers of individuals are obese; almost a quarter of adults are affected (23 % of men and 24 % of women) [1, 2].

As overweight is so prevalent, it would be of great interest to identify the factors that influence weight gain, as well as successful weight loss and weight maintenance. It might then be possible to infer possible methods for treatment or prevention. At the first glance, it is quite clear how to lose weight: Energy intake must be less than energy expenditure. There has been much debate about the best way to reach this goal. For decades, there has been a great deal of discussion and research on changes in the composition of food with respect to the content of the energy sources carbohydrate, fat and protein. However, this approach could be incomplete or misleading if the energy density is ignored [3].

The present statement presents the principle for the calculation and assessment of the energy density of foods. Current scientific knowledge on the link between food energy density and body weight is described and evaluated. For this purpose, a literature search was carried out in PubMed for meta-analyses and systematic reviews. In addition, for the period between 1 May 2011 (end of the search period for the most modern available meta-analysis) and 25

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June 2013, a search was performed for intervention and cohort studies (search terms: ["energy density" OR "caloric density" OR "energy dense"] AND ["body weight" OR "body mass index" OR obes* OR overweight OR adiposity]; Limits: Humans; Field: Title / Abstract). ◆ Table 2 summarises the selected studies that were used in this statement to evaluate the available data.

Most natural foods of plant origin exhibit low energy density and high nutrient density – the exceptions are plant oils and nuts. Because of their high water content, drinks and fluid dishes – such as soups – exhibit lower energy density than many "solid" foods and dishes. This is illustrated in ◆ Figure 1, with the energy density of selected foods and dishes.

Definitions

Energy density is defined as the energy content (in kcal or kJ) per unit weight (e.g. g or 100 g) food.

Nutrient density is the ratio of essential nutrients to energy in the food. This is defined as the quantity of nutrient (e.g. in mg) per unit energy (e.g. kJ or MJ).

Energy density of foods and dishes

Foods or dishes of low energy density provide less energy per unit weight than those with high energy density. For the same amount of energy, a person can consume a larger portion of a food or dish of low energy density than of one with a high energy density.

The energy density of foods and dishes, or diets, is largely dependent on their fat and water content [4]. If a food is rich in water (provides no energy) or in fibre (low energy content of ca. 2.3 kcal/g), it generally exhibits low energy density. Vegetables and fruit are the best example of this. In contrast, foods that are rich in fat usually exhibit high energy density, as fat is the nutrient with the highest energy density (fat, 9 kcal [37 kJ]; alcohol, 7 kcal [29 kJ]; carbohydrate, 4 kcal [17 kJ]; protein, 4 kcal [17 kJ] – each per g). However, foods rich in carbohydrate can also exhibit high energy density, if the water content is low – e. g. white bread.

Calculation of the mean energy density of food on the basis of food consumption in Germany

Energy density of food for adults, depending on age and gender

The National Nutrition Survey II (NVS II) provides representative data on food consumption and nutritional behaviour for the German-speaking population. In the context of NVS II, a total of 19,329 men and women aged 14–80 years were surveyed throughout Germany between November 2005 and January 2007. On the basis of two 24-hour recalls, weighted data were available for 10,215 adults (19–64 years) (◆ Table 1). Drinks were not considered in the calculation of energy density. The median energy density was 1.7 kcal/g for women and 2 kcal/g for men [6].

When considering these data, it is important to remember that participants may underreport their own food consumption in a 24-hour recall (underreporting, see the section on "Method to determine the energy density of food", p. 4). Calculations of the energy density on the basis of consumption data from agricultural statistics and income and consumption samples (potential overestimation of the true consumption) give lower values for the mean energy density (women ca. 1.4 kcal/g, men ca. 1.8 kcal/g) [7].

Energy density of food, depending on lifestyle and nutritional knowledge

National Nutrition Survey II (2012) describes the evaluation of the 24-hour recall data from 6,817 participants in the NVS II, aged 19 to 64 years for different population groups. This gave the following results for the food energy density (drinks were excluded from the calculation) [8]:

– For women and men who engage in sport, the median food energy density is lower (1.64 kcal/g and 1.94 kcal/g, respectively) than for

	19–24 years		25–34 years		35–50 years		51–64 years		overall	
	n	**P50**	n	**P50**	n	**P50**	n	**P50**	n	**P50**
women	486	1.88	852	1.71	2 648	1.71	1 740	1.58	5 726	1.70
men	469	2.17	614	2.08	1 946	2.03	1 460	1.92	4 489	2.02

Tab. 1: **Median values (P50) for food energy density [kcal/g] by gender and age** (data from NVS II [6])

those who do not engage in sport (1.73 kcal/g and 2.02 kcal/g, respectively).

- For female and male smokers, the median food energy density is higher (1.80 kcal/g and 2.11 kcal/g, respectively) than for female and male non-smokers (1.63 kcal/g and 1.93 kcal/g, respectively).
- For women and men who take food supplements, the median food energy density is lower (1.61 kcal/g and 1.92 kcal/g, respectively) than for women and men who take no supplements (1.70 kcal/g and 2.01 kcal/g, respectively).
- If women and men know more about nutrition, their median energy density is lower (1.62 kcal/g and 1.85 kcal/g, respectively) than for women and men who know little about nutrition (1.74 kcal/g and 2.00 kcal/g, respectively).
- For women with very good or good cooking skills, the food energy density is lower (1.65 kcal/g) than for women with little or no cooking skills (1.81 kcal/g).
- Women and men who were not born in Germany have a lower mean energy density (1.58 kcal/g and 1.87 kcal/g, respectively) than women and men born in Germany (1.69 kcal/g and 2.00 kcal/g).

Energy density and food prices

In Germany and in other countries, foods of high energy density are relatively cheap [9–12]. In other words, foods of high energy density provide energy cheaply, while foods of lower energy density cost more per unit energy (€/kcal). It is therefore probable that foods of high energy density are mainly consumed when income is low (based on a selection by price per weight or portion). The relatively low prices of foods of high energy density may be one reason for the high prevalence of overweight in the population, particularly for consumers of low socioeconomic status [9], whose risk of obesity is increased [13]. Conversely, food of high quality frequently costs more per kcal and is consumed by persons with a higher level of education [14].

In a randomised controlled study in two supermarkets in Manhattan, it was established that cheap offers (50 % price discount) of vegetables and fruit (foods of low energy density) increased the sales and consumption of these foods [15].

Link between energy density and body weight

Method to determine food energy density

The energy density of food can be determined by various methods. For example, it can be exclusively calculated on the basis of food consumed without drinks, on the basis of food consumed including energy containing drinks, or on the basis of all food consumed, including all drinks.

Johnson et al. (2009) [16] proposed the hypothesis that the inclusion of drinks in the calculation of food energy density attenuates the recognisable effect of energy density on body weight. They postulate that studies on the correlation between energy density and the risk of weight increase should be based on the energy density of foods without drinks. This is because their systematic evaluation of the studies showed that the effect of energy density on weight increase is due to changes in the composition of foods and not of the drinks consumed. If the energy density including drinks is calculated, this gives a variable that shifts the association between energy density and weight increase in the population in the direction of no correlation. Moreover, the intra-individual between-day variance may then be greater than the inter-individual variance if the energy density of foods including drinks is calculated.

However, the energy supply from drinks cannot be neglected as an important factor in the development of overweight. It should be characterised and used as a covariate in risk assessment. According to Johnson et al. (2009) [16], standardisation of these methodological aspects would facilitate the interpretation of the scientific data to develop evidence-based measures for overweight prevention.

Another critical aspect in the determination of food energy density and its correlation with body weight is underreporting. In many cases, nutritional data are based on self-reporting by the participants; the information on energy supply is less reliable than the recording of other nutritional factors. Particularly overweight persons tend to underestimate their consumption of high energy foods and thus their energy consumption [17–19]. Moreover, there is also evidence that underreporting in the overweight is particularly common for foods of high fat and sugar content, i. e. generally those of high energy density [20–22]. In addition, self-reported data on body weight tend to underestimate the actual value and the extent of underreporting is proportional to the overweight of the individual [23, 24].

This putative underreporting could lead to an underestimate of the correlation between energy density and body weight. For this reason, the following results must be regarded as a conservative estimate – the true effect size could be greater.

(continued p. 7)

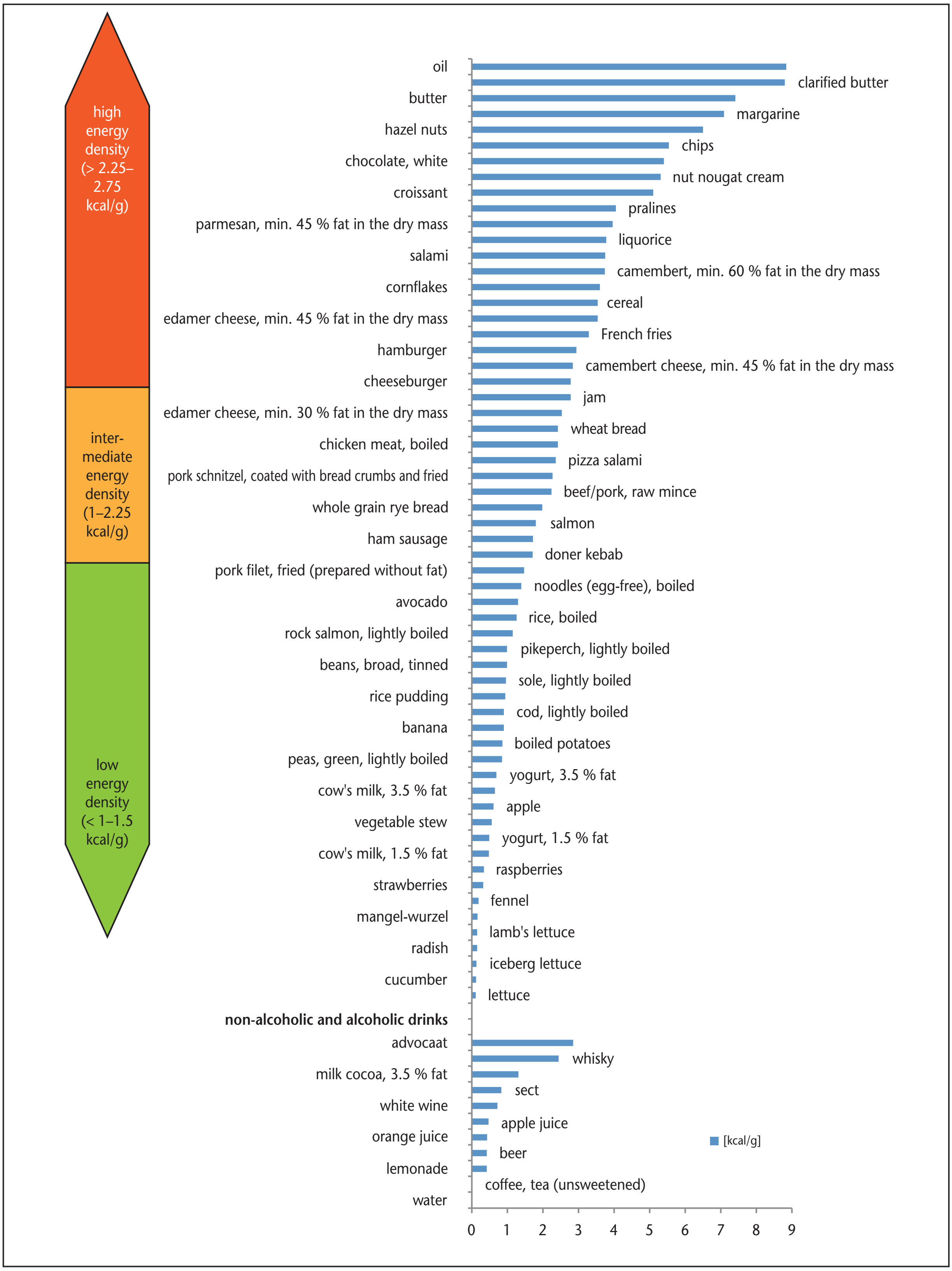

Fig. 1: **Energy density [kcal/g] of examples of foods and dishes. The values range from 0 kcal/g for water to 9 kcal/g for fat or oil** (Source: DGExpert Version 1.3.0.1). Classified into high, intermediate or low energy density by the World Cancer Research Fund (2012) [5]

Study (Author, Year)	Study Type	Study Population	Duration (Follow-up)	Exposure	Outcome variables	Methods/ Statistical Analysis	Result
Johnson et al. 2009 [16]	**systematic review** of 8 cohort studies and 16 cross-sectional studies	between 9 and 191,023 children and adults (m and/or f) per study under their normal living conditions, who did not actively wish to lose weight and who were not clinically ill	not given	ED of the food with versus without drinks, recorded with the nutrition protocol, 24-hour recall or FFQ	body weight and composition, validity of different ED calculation methods	systematic literature search in MEDLINE till 1 September 2008 and manual search	studies on the correlation between ED and body weight should be based on an analysis of food ED without drinks, incorporating the energy supply from drinks as covariate
Melanson et al. 2012 [29]	**randomised clinical intervention study**	157 overweight women and men (BMI 31.8 + 2.2, age 38.7 + 6.7 years), participants in a commercial weight reduction program	12 weeks	instructions on a) low ED b) low glycaemic index c) control of portion size	body weight and composition, risk factors for metabolic syndrome, energy and nutrient supply	Δ body weight	mean (SD) a) –4.14 (3.64), b) –3.39 (2.76), c) –3.73 (2.84); p = 0.509
						Δ BMI	a) –1.36 (1.34), b) –1.11 (1.04), c) –1.32 (1.03); p = 0.539
						Δ body fat (%)	a) –3.87 (3.34), b) –2.65 (2.97), c) –2.91(2.59); p = 0.167
						ED after 12 weeks (kJ/g)	a) 3.68 (1.38), b) 3.89 (1.38), c) 4.02 (1.05); p = 0.512
Perez-Escamilla et al. 2012 [26]	**systematic review** of 17 intervention and cohort studies in adults and 6 cohort studies in children	between 23 and 89,432 children, adolescents and adults (m and f or f) per study	between 4 weeks and 4 years (intervention) and between 6 months and 12 years (cohorts)	ED of food (with or without drinks or without giving the ED calculation method)	body weight, BMI, weight of body fat	systematic literature search in PubMed for the period January 1980 to May 2011; up-dated to the 2010 DGAC report [27]	adults: strong and consistent evidence for a positive association between ED and body weight children and adolescents: moderately strong evidence for a positive association between ED and obesity
Raynor et al. 2012 [28]	**randomised controlled intervention study** (pilot study)	44 overweight women (82 %) and men (BMI 34.8 + 4.8, age 52.1 + 7.6 years)	12 weeks	instructions on a) low ED b) low energy and fat content c) low ED with low energy and fat content	weight loss, food and nutrient supply (nutritional quality)	intention-to-treat Δ body weight (lb)	mean (SD) a) –20.5 (7.0) b) –16.9 (10.1) c) –12.5 (6.5); p < 0.05
Wilks et al.2011 [25]	**meta-analysis** of 6 prospective cohort studies	between 48 and 1,762 children and adolescents (m and/or f) per study for analysis	ca. 9 months to 7 years	ED of food (apart from drinks) recorded with food protocol, 24-hour recall or FFQ	body fat content	source of the included studies: earlier systematic review with bias-adjustment meta-analysis (adjustment for differences in study design and quality by incorporation of expert opinions)	pooled correlation estimates: a) unadjusted: 0.06 (95 %-CI: 0.01–0.11; p = 0.013) (heterogeneity) b) adjusted for internal bias (study quality): 0.14 (95 %-CI: –0.06–0.34; p = 0.16) c) adjustment for internal and external biases (adjustment for specified objectives): 0.17 (95 %-CI: –0.11–0.45; p = 0.24)

Tab. 2: **Characteristics of the studies incorporated in the evaluation of the correlation between energy density and body weight**
Δ = change, 95 %-CI = 95 %-confidence interval; BMI = body mass index; ED = energy density; f = women; FFQ = food frequency questionnaire; kJ = Kilojoule (1 kJ = 0.239 kcal); lb = Pound (1 lb = ca. 0.45 kg); m = men; SD = standard deviation

(Continuation from p. 4)

Results of epidemiological studies

In order to evaluate the evidence for the correlation between nutritional energy density and body weight, a meta-analysis has been performed [25] on six prospective studies. These studies had also been included in a systematic review in 2009 [16]. Five of these studies were also evaluated in a recent systematic review [26] of 17 interventional and cohort studies with adults and 6 cohort studies with children and adolescents.

In their narrative systematic review, JOHNSON et al. (2009) [16] stated that most prospective observational studies indicated a positive association between energy density and obesity in adults and children, although there were considerable differences between the individual studies with respect to design and quality. The differences included the age of the participants, the follow-up observational period (between 9 months and 7 years), whether the energy density was incorporated in the statistical analysis as a continuous or categorical variable, the calculation of the energy density (food without drinks, food and all drinks, or food and energy containing drinks, see the section on "Method to determine food energy density", p. 4), the determination of body weight status (e. g. body weight or weight of body fat), as well as adjustment for confounders. For this reason, JOHNSON et al. were unable to calculate an overall effect size [16].

WILKS et al. (2011) [25] applied an adapted meta-analysis method, that allows adjustment for differences in study design and quality by using a formal transparent process of incorporation of expert opinions (bias-adjustment meta-analysis). The key question in their meta-analysis was as follows: "Is the energy density (excluding drinks) associated with changes in the weight of body fat in children?" The results of the studies were converted to correlation coefficients without adjustment. The correlation estimate was then 0.06 (95 %-confidence interval [95 %-CI] 0.01–0.11; p = 0.013), with heterogeneity between the studies. After adjustment for internal biases (study quality), the studies were comparable and the pooled correlation was then 0.14 (95 %-CI -0.06– 0.34; p = 0.16). After adjustment for both internal and external biases (adaptation to the specified targets for the meta-analysis), the pooled correlation between energy density and the change in the weight of body fat in children was 0.17 (95 %-CI -0.11–0.45; p = 0.24). Thus, the studies were comparable after these adjustments, but the association was no longer statistically significant. The correlation coefficient was increased in comparison to the non-adjusted analysis; according to WILKS et al., this indicates that the energy density is possibly an important determinant of excessive weight increase. They called on decision makers to carry out interventions to reduce energy density, in order to reduce overweight in children, as well as drawing the attention of consumers to the importance of reduced energy density [25].

In the 2010 Dietary Guidelines for Americans, the Dietary Guidelines Advisory Committee (DGAC) of the US Department of Agriculture (USDA) indicated that the total energy intake is the decisive nutritional factor for body weight control and that it is easier to control body weight with food of lower energy density. They considered that there is strong and consistent evidence that energy density is positively associated with obesity in children and that a nutritional pattern of relatively low energy density can improve weight loss and weight maintenance in adults [27]. This DGAC evaluation was based on the evidence-based systematic reviews prepared with the support of the Nutrition Evidence Library (NEL) of the USDA and up-dated by PÉREZ-ESCAMILLA et al. (2012) [26] with the inclusion of studies published from January 1980 to May 2011.

The 17 studies included had between 23 and 89 432 **adults** and investigated the relationship between energy density and **weight loss in the overweight or obese**. Seven of these studies were randomised controlled intervention trials (RCTs) and one involved a non-controlled intervention. Nine studies were cohort studies on the correlation between energy density and body weight status or maintenance in normal weight, overweight and obese adults. The methods used to calculate energy density were different, or, in some cases, unspecified. In addition, the methods to reduce energy density in the interventions also differed (e. g. nutritional advice, provision of foods of lower energy density). Four of the seven RCTs found significantly greater weight loss with reduced energy density (calculated with foods without drinks). One RCT found that a snack of high energy density together with meals led to weight gain, but that a snack of low energy density had no effect. Two RCTs found no difference in weight loss between nutrition with high versus low energy density. The prospective cohort studies found a consistent positive association between **low energy density** and **lower weight increase or BMI, better weight maintenance and/or weight loss.**

Six prospective cohort studies included between 48 and 2,275 normal weight and overweight **children and adolescents** and follow-up periods of one to twelve years; they also calculated energy density in various ways. Four of these six studies found a positive association between energy density and obesity; one study found no association and one an inverse association.

Overall, PÉREZ-ESCAMILLA et al. (2012) [26] confirmed the results of the DGAC (2010) [27] and concluded that there is strong and consistent evidence from interventional and prospective cohort studies for a positive association between energy density and body weight and that nutrition with relatively low energy density improves weight loss and maintenance. For children and adolescents, there is moderately strong evidence from longitudinal studies for a positive association between energy density and obesity [26].

A pilot study was published after these systematic reviews and meta-analysis. It had a randomised controlled design and lasted for 12 weeks. Lifestyle intervention was in the form of instructions on nutrition with a) low energy density, b) low energy and fat content or c) low energy density with low energy and fat content. The effects of these interventions were measured on the quality of nutrition and weight loss in 44 overweight adults (BMI 34.8 ± 4.8). The instruction on nutrition with low energy density (a) enhanced the consumption of fruit and increased weight loss in comparison to the other instructions [28].

In another 12-week randomised interventional study, 157 overweight participants (BMI 31.8 ± 2.2) in a weight reduction program (Weight Watchers) were given a nutritional plan with individual advice on either: a) low energy density, b) low glycaemic index, or c) control of the portion size. The effects were then examined, including body weight and composition. All methods led to a loss in body weight and body fat, although the differences between the three groups were not significant [29].

Discussion and conclusions

The weight of scientific evidence indicates that there is a positive correlation between food energy density and body weight. A nutritional pattern with low energy density can have a positive effect on changes in body weight.

The energy density of the food consumed is an important determinant of the total energy intake. Experimental studies show that a low food energy density leads to lower energy intake during *ad libitum* nutrition in both adults and children [30–41]. Short term studies in adults have shown that the consumption of foods with lower energy density leads to increased satiation [31, 40]. The acute regulation of satiation and hunger is primarily determined by the volume of food, so that the energy intake at constant satiation volume is primarily dependent on the energy density in this volume [3, 42, 43]. In children and adolescents, the scientific data indicates that the consumption of energy dense foods can lead to passive consumption of excessive energy [36, 44–46].

The high frequency of overweight is influenced in a complex manner by many factors [47]. Many studies show that one of these factors is a high consumption of foods of high energy density. Scientific societies and health organisations throughout the world recommend that energy density should be reduced for weight control – both for adults and for children [48–53].

The DGE also concludes that measures for weight control should consider food energy density. If food energy density is lower, the energy intake is less when large quantities of food are eaten. This can help to increase compliance with nutritional recommendations.

The strategy to reduce nutritional energy density is to increase the consumption of foods with high levels of water and fibre – such as vegetables and fruit – and to reduce the consumption of foods with high levels of fat or added sugar, as well as energy containing drinks (alcoholic drinks, juices and nectars, sugared soft drinks). A nutritional pattern with lower energy density is thus also one with high nutrient density, that is high nutritional value. A healthy nutrition pattern with low energy density includes the consumption of low quantities of foods of high energy density, such as rape oil or nuts. The orientation for the selection of foods can be provided by the three dimensional food pyramid, which classifies foods in accordance with their nutritional physiological quality, incorporating the energy density as a criterion for evaluation [54].

Selection of healthy foods with consideration of energy density does not mean then that foods of high energy density are excluded in principle. Moreover, simple replacement of foods of high energy density with those of low energy density is not sensible – unless they belong to the same product group, e. g. sausages. What is important is that foods of low and intermediate energy density should be the basis of daily nutrition and that consumption of foods of high energy density should be limited. One criticism of the concept of energy density is that the roles of different high density foods must be differentiated. Plant oils and nuts are energy dense, but are nevertheless of value for nutritional physiology. Fat and sugar are often added during the preparation of products such as crisps, pastries and sweets. These are energy dense, but have very low nutrient density. The concept of energy density does not cover this aspect adequately and it must be examined how this aspect can be integrated into concept of energy density.

In comparison to many solid foods, energy containing drinks, such as sugared soft drinks, have a relatively low energy density (◆Figure 1). However, the energy and sugar supplied by sugared drinks, juices and nectars, as well as alcoholic drinks, should not be neglected. The consumption of sugared drinks is an important factor in the development of overweight and type 2 diabetes [55]. Even a higher consumption of fruit juices (as opposed to fruit) is associated with a higher risk for type 2 diabetes mellitus. Consumption of high levels of fruit juice (in contrast to fruit) is associated with an increased risk of type 2 diabetes [56]. In comparison to similar solid foods, high energy drinks presumably cause less satiation, which tends to increase energy intake [57–59]. It is still unclear how drinks should best be considered in studies on the correlation between energy density and body weight [26]. It may nevertheless be concluded that energy density is a useful concept in the evaluation of foods aside from drinks, if nutrient density is also considered. It is generally true that drinks should only make up a small part of the total energy supply. In other words, energy-free drinks such as water and unsweetened tea should be preferred.

As tasty energy dense foods are cheap and almost always available, it is difficult today for many consumers – particularly those of low socioeconomic status – to adapt their daily nutrition to their individual requirements. As shown by the data described from the NVS II (see the section "Calculation of the mean energy density of food on the basis of food consumption in Germany" p. 3), improvements in nutritional knowledge and cooking skills and a healthy lifestyle are generally accompanied by lower food energy density. This demonstrates the importance of active nutritional and consumer education [60]. It is not yet conclusively clear and has to be further investigated whether changes in the price structure of foods can influence food selection and eating behaviour as desired, that means support the selection and consumption of less energy dense foods and, in general, the selection of healthy foods [9, 61].

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Conflict of Interest

The author declares that there is no conflict of interest according to the guidelines of the International Committee of Medical Journal Editors.

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