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REVIEW

Food intake patterns and body mass index in observational studies

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OBJECTIVE: To review studies of patterns of food intake, as assessed by diet index, factor analysis or cluster analysis, and their associations with body mass index or obesity (BMI/Ob).
DESIGN: Systematic literature review MEDLINE search with crosscheck of references.
STUDIES: Thirty observational studies relating food intake patterns to anthropometric information were identified and reviewed. Food intake patterns were defined using a diet index, factor or cluster analysis in 12, nine and nine studies, respectively. Measures of body mass were made concurrently with the diet assessment in all studies, and only in a few cases were the primary outcomes related to BMI/Ob.
RESULTS: The food intake patterns identified could, in most factor or cluster analysis studies, be categorised as: (a) meat, fatty, sweet or energy dense foods; (b) vegetables, fruit, whole grain and low-fat foods; or (c) by high alcohol consumption. The diet indexes were designed to capture a high diversity and/or food combinations matching the recommendations.
The relationships with BMI/Ob were inconsistent — ten studies found that intake patterns, which we categorised as fatty, sweet or energy dense were positively associated with BMI/Ob, while similar patterns in four other studies were negatively associated with BMI. The significant associations between diet index score and BMI/Ob were consistently negative, while the associations between factor scores or cluster membership and BMI/Ob were less clear in terms of food intake pattern. Men and women had similar food intake patterns, but food intake patterns were less often positively associated with BMI/Ob in women. In 11 studies, there were no significant associations between food intake pattern and BMI/Ob.
CONCLUSION: This review showed that no consistent associations could be identified between BMI or Ob and food intake patterns, derived from diet index, factor analysis or cluster analysis. However, the heterogeneity of food intake patterns identified by such analyses and the lack of gold standards for the application of these techniques hampers consistent analysis of a relation between food intake patterns and health.
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Keywords: diet; factor analysis; cluster analysis; diet index; review

Introduction

It has proved difficult to show what has caused the epidemic increase in the prevalence of obesity, which now is seen in most countries.[1] Several studies have examined relations between nutrients, particularly dietary fat, and obesity, but the epidemiological evidence remains controversial. In a review of studies associating dietary fat with obesity,[2] the authors concluded that, in cross-sectional and short-term experimental studies, the energy percentage from fat in the diet was associated with obesity, whereas prospective studies of fat intake in relation to subsequent weight-change gave inconsistent results, also when properly taking into account potentially confounding co-variables.[3] Willett[4] pointed out that there was no evidence linking a high dietary fat intake on the long-term to obesity. Likewise, the divergent trends in obesity and fat intake seen in most countries (eg the US) seem paradoxical.[5]

The focus on nutrients has the advantage of simplicity by using only one single figure (eg ‘percentage energy from fat’ or ‘grams of fibre’), as opposed to the expected more complex output from analyses of food intake patterns. However, the nutrient-effect approach may be too simplistic, since each meal comprises a mixture of several foods, which in

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turn are composed of many nutrients in different amounts. By analysing intake of foods or food groups in conjunction with other foods, the potential effect of known and unknown interactions within such conglomerate of foods and thereby nutrients may be taken into account. Furthermore, from a public health perspective, the combinations of immediately identifiable foods may be more useful as basis for recommendations with regard to avoiding obesity development.

Therefore the focus has shifted from a nutrient-based approach to that of describing food intake patterns.[6] In the present paper, food intake pattern was defined as *'the distribution (by frequency and/or amount) of foods in the habitual diet'* (as distinct from meal patterns).

A comprehensive review from 1996[7] summarised 55 studies using broadly defined indexes of overall diet quality (based on diet index, and factor, and cluster analysis), but it did not have a particular focus on obesity. It did, however, find that the diet indexes were related to the risk of some diseases more strongly than individual nutrients or foods, which emphasises the usefulness of this approach.

Objective

The objective of the present literature survey was to compare patterns of food intake and their associations with obesity or, as a measure of fatness, body mass index (BMI = weight/height^2 (kg/m^2)) from studies using the scoring techniques: diet index, factor analysis or cluster analysis. We hypothesised that a more consistent picture would emerge from relating food intake patterns to obesity than that reported by others for nutrients and obesity.

Special attention was paid to the following questions:

- How were the scoring techniques employed?
- Were associations between BMI or obesity and food intake patterns similar in different studies?
- What problems had to be dealt with when analysing food intake data for patterns?

The scoring techniques

The focus of this study is not statistical, and hence a detailed discussion of the techniques is not included. Instead we refer to the statistical literature (for an introduction to cluster, factor and other latent variables analyses we suggest reading the books by Aldenderfer,[8] Kline[9] and Loehlin[10] or other relevant textbooks).

Two fundamentally different approaches are used for scoring food intake patterns in observational epidemiological studies, *a priori* methods and *a posteriori* methods.

A priori methods

A priori methods explore the data using predefined combinations of foods in a diet index. This *diet index* is based on knowledge from previous studies or from deduction. Such indexes typically group or rank subjects by their computed score into the 'healthier' or the 'less healthy' eaters. The index is one categorical variable if the indicator food variables are all binary or categorical (eg below or above population median of food intake), or a continuous variable if some of the indicators are continuous (eg grams of food). Examples are the Healthy Eating Index[11] or the Diet Diversity Score.[12]

A posteriori methods

These methods explore the available data *post hoc* by either factor or cluster analysis and use the results for scoring within the same study. The first example we found of this was an international 'ecological' analysis of per capita food consumption and cancer mortality data, relating particular cancers to particular food choices/factors.[13]

Factor analysis has been described as 'a multivariable method intended to explain relationships among several difficult-to-interpret, correlated variables in terms of a few conceptually meaningful, and relatively independent factors'.[14] The theory is that habitual intake of indicator foods (eg a subset of the dietary variables included in a food frequency questionnaire (FFQ)) is explained, to some extent, by a number of latent (ie not directly measurable) variables that influence the food intake. The purpose of an exploratory factor analysis is to identify factors that are measurable estimates of the 'true' latent variables and can be described as a correlation-based construct of the weightings (or loadings, usually standardised to a value between - 1 and 1) of each indicator food. Subsequent to the extraction of the factors (the number of which is determined in advance possibly by principal component analysis), a score (a weighed sum that can be calculated in various ways depending on the standardisation method used) is computed for each of the subjects in the various factors. The scores are used to identify individual agreement with each diet pattern, and in further analyses to compare with regard to outcomes (eg morbidity).

In cluster analysis subjects are grouped into clusters by the use of algorithms devised to minimise inter-cluster-correlation of diet variables. This procedure uses nutrient variables, food or food group variables, or combinations of them as input (indicator variables). To what extent a subject resembles the mean value of the indicator variables, on which the clustering is made, can be computed as the 'distance-to-cluster-mean' variable. The number of clusters must be given in advance; typically as the most plausible of a number of tested options. Ideally, this approach discloses clusters of subjects with similar diets, which can be compared to other characteristics such as risk factors, or morbidity or mortality. Thus, the question is raised whether the mean BMI or the prevalence of obesity is higher in one cluster than in the others.

Comparison of the methods

The difference between the three methods can be illustrated by their output to further analysis. The diet index is usually one quantitative variable (ie a score on which subjects are ranked) with a predefined food intake pattern 'quality'. The factor analysis has two major outputs: the loadings of foods on each factor (the qualitative aspect) and the factor scores (the quantitative aspect) for each factor–subject combination. Finally, in the cluster analysis, the quantitative aspect is a categorical variable for exclusive cluster-membership, and the quality of each cluster can be described by mean indicator food values in each cluster.

Some variants of the factor and cluster methods are less '*a posteriori*'. In the confirmative factor analysis some foods can be correlated with one factor only and some with another (optionally start-values for loadings can be indexed prior to estimation), thereby allowing a better control of the food intake factors in the analysis. In cluster analysis the 'cluster centres' (mean indicator values for clusters around which subjects are clustered) can be given in advance — optionally as starting values only — whereby the quality of the clusters become less determined by the current data. These options are not used (at least not reported) in any of the papers reviewed.

Retrieval and selection of papers

A search in MEDLINE® was conducted, using the following key-words: diet, diet choice, diet habits, diet index, diet patterns, diet intake patterns, food choice, food habits, food groups, food patterns, food preferences, food index, factor analysis, cluster analysis and principal component analyses. In addition, all identified pertinent papers were searched for related references.

The papers were selected only (a) if the diet patterns were based on or described by individual intake of foods or food groups (hence the title *food* intake patterns) and not only nutrients, (b) if they included a majority of adults, and (c) if they were published in English before February 2001. Furthermore, only studies, where the major outcome was obesity or where BMI/body fatness was compared over food intake patterns, were included.

We did not include papers concerning only the *temporal* aspect of food intake (ie when and/or in how many portions

Table 1 Characteristics of the reviewed diet index studies

Reference and setting, sorted by publication year	*Design*[a]	*Subjects, gender*[a]	*Age*	*Diet method*[a]	*Input (type)*
I-1 Gates *et al* (1975) US University of California[15]	CS (covert observation of diet and body build)	360 m/360 w	30 – *vs* 30 +	Observation. 1 meal.	15 F
I-2 Kant *et al* (1991) US NHANES II '76–80[19]	CS	5509 m/6020 w	25–74	24 h	5 F
I-3 Kant *et al* (1993/1995) US, NHANES I '71–75[20,39]	Baseline CS information in PS study	4160 m/6264 w	25–74	24 h	5 F
I-4 Kennedy *et al* (1995) US, CSFII '89,'90[11]	CS	7463 m + w	2 +	24 h and 2 day record	10 F/N incl. variety %
I-5 Gibson (1996) UK DNSBA '86–87[23]	CS (BMI measured after 7 day diet-record)	1087 m/1110 w	16–64	Weighed 7 day record	51 F
I-6 Slattery *et al* (1997) US, California/Utah/Minnesota[21]	CC (colon cancer cases, BMI stratification in diet analysis)	2387 m/2014 w	30–79	'DHQ', 12 months	69 F
I-7 Kayrooz *et al* (1998) US, Maryland, Afro-Americans[24]	CS (sample of attendees at health fair)	521 w	18–91	12 dietary habits	12 C
I-8 McCrory *et al* (1999) US, Massachusetts[22]	CS	13 m/58 w	20–80	FFQ, 6 months	8 F
I-9 Kant *et al* (2000) 27 cities in US (BCDDP)[6]	Baseline CS information in PS study	42254 w	47–86 (approx.)	FFQ, 12 months	23 F
I-10 Kant (2000) US (NHANES III)[16]	CS	7470 m/8141	≥ 20	24 h	5 F
McCullough *et al* (2000), US I-11 Nurses health study[17] I-12 Male health professionals[18]	Baseline CS information in PS study	67272 w 38622 m	30–55 40–75	FFQ, 12 months	10 F/N 10 F/N incl. variety %

[a]*Notes: Design* — CS = cross-sectional, PS = prospective, BMI = body mass index, CC = case–control; *Gender* — m = men, w = women; *Diet method* — D-H = diet history, DHQ = diet history questionnaire, FFQ = food frequency questionnaire, 24 h = 24 h recall, Observation = observation in cafeteria. Reference period given if available, *Input* — F = foods or food groups, C = components in questionnaire (eg questions about fat usage), N = nutrients (protein, fat, subtypes of fat, sugar, vitamins etc) or energy measures.

the food was eaten during the day = meal patterns), or type and proportion of foods eaten between meals (ie snacking). We excluded such studies in order to ease comparison of studies and to focus the review on the overall food intake pattern.

Material

In total we identified 108 studies using one of the three scoring techniques in studies of diet patterns with or without anthropometric information. In the previously mentioned review by Kant, six studies of associations between food or food group based diet patterns *and* relative weight were included.[7] In addition we have been able to identify 24 other studies (nine simple diet index, eight factor analysis and seven cluster analysis studies) that included associations with measures of relative weight or body fat mass.

Methods used in the reviewed studies

Tables 1–3 list the main characteristics for each of the 30 studies included, and describe the elements and methods used for scoring. In all studies reviewed, anthropometric measurements and the diet assessment were carried out concurrently (cross-sectional design), even though some of the studies had a prospective design with regard to the major outcome, and some were part of a case–control study.

Methods and variables used to identify food intake patterns

Diet indexes. Twelve studies were identified (Table 1); five to 69 foods or nutrients were used as input in the indexes. The recommendations behind the indexes were different (Table 4): good nutritional value;[11,15–18] high diversity defined as as many different foods as possible (within a given category)[6,19–22] or low fat, sugar or animal-food intake.[21,23,24] The indexes were computed as a sum of points (eg on diversity, or using a fat intake scale), as a ratio (eg A foods *vs* B foods), as a ratio of proportions (eg percentage animal foods divided by percentage plant foods) or by the combination of foods and cut-off points (eg low-fat and high-sugar diet).

Factor analyses. In total nine studies were identified (Table 2). In these studies 18–95 foods or food groups were entered in the analysis as units per time or FFQ categories. The number of factors was determined by the amount of variation explained by that number of factors and how much further variation could be explained by inclusion of more factors. The resulting two to seven factors explained a total of 20–59% of the variance, the differences being partly related to the number of foods per factor (the more foods the less explained variance). Interpretation of the loading pattern of foods on the factors has led to the labels for each factor listed in Table 5.

Table 2 Characteristics of the reviewed factor analysis studies

Reference and setting sorted by publication year	*Design*[a]	*Subjects, gender*[a]	*Age*	*Diet method*[a]	*Input (measure)*[a]	*Number of factors*
F-1 Gex-Fabry *et al* (1988) Switzerland-Geneva[34]	CS (random population sample)	556 m/383 w	19–75+	D-H, 'usual'	33 F (g/week)	3
F-2 Barker *et al* (1990) Northern Ireland[35]	CS (random population sample)	258 m/334 w	16–64	Weighed 7 day record	41 F (g)	4
F-3 Randall *et al* (1992, 1991) US — Western NY[52,38]	CC (only controls in BMI–diet correlation analysis)	410 m + 446 w	<50–>80	FFQ, 12 months	95 F (score/year)	7
F-4 Wolff *et al* (1995) Mexican-American HHANES (Hispanic)[36]	CS diet/BMI (RS: infant birth weight)	549 w	24.2 (mean)	FFQ, 'usual'	18 F (frequency/day)	7
F-5 Beaudry *et al* (1998) Canada-Quebec Provincial Nutrition Survey[43]	CS	1033 m/1071 w	18–74	24 h	30 F (g)	3
F-6 Gittelsohn *et al* (1998) Canada Natives (Ojibwa-Cree Community)[42]	CS (71% of total community)	210 m/268 w/ 243 children	37 (adult mean)	FFQ, 3 months	34 F (score)	7
F-7 Slattery *et al* (1998) US — Western states[37]	CC (only controls in BMI–diet correlation)	2389 m + 2014 w	30–79	D-H, 'usual'	35 F (items)	6
F-8 Hu *et al* (2000) US Health professionals[40]	Baseline CS information in PS study	44875 m	40–75	FFQ, 12 months	40 F (servings/day)	2 (of 3)
F-9 Fung *et al* (2001) US Health Professionals[41]	CS information in PS study	466 m (sub-sample)	40–75	FFQ, 12 months	42 F (servings/day)	2 (of ?)

[a]Notes: *Design* — CS = cross-sectional, BMI = body mass index, RS = retrospective, PS = prospective, CC = case–control; *Gender* — m = men, w = women; *Diet method* — D-H = diet history, FFQ = food frequency questionnaire, 24 h = 24 h recall, reference period given if available; *Input* — F = foods or food groups.

Table 3 Characteristics of the reviewed cluster analysis studies

Reference and setting[a], *sorted by publication year*	*Design*[a]	*Subjects, gender*[a]	*Age*	*Diet method*[a]	*Number of input (type)*[a]	*Number of clusters and foods used for description*
C-1 Farchi *et al* (1989) Italy, North/central[25]	CS information in PS study	1536 m	45–64	D-H	7 N (standardised)	4 clusters, 14 foods
C-2 Hulshof *et al* (1992) Netherlands, (DNFCS)[27]	CS	1802 m/1979 w	19–85	2 day record by dietician	6 N (weighed scoring system)	3 of 8 clusters described by 26 foods
C-3 Tucker *et al* (1992) US, Boston[31]	CS	233 m/447 w	60+	3 day record	16 F (proportion of energy)	4 clusters, 16 foods
C-4 Huijbregts *et al* (1995) Netherlands, Zutphen study[26]	CS information in PS study	518 m	70–89	D-H, 'usual'	9 N (standardised)	4 clusters, 17 foods
C-5 Schroll *et al* (1996) SENECA: B, DK, F(×2), I, NL, P, E, CH[33]	CS information in PS study (at follow-up)	502 m + 471 w	74–79	D-H, 1 month	8 N, S (standardised)	4+5 clusters, 10 foods (+6 N)
C-6 Wirfalt *et al* (1997) US, Minnesota, Minneapolis[32]	CS (pooled information from three studies)	200 m/326 w	37 (mean)	FFQ 60 items 12 months (?)	38 F (proportion of energy)	6 clusters, 38 foods
C-7 Fraser *et al* (2000) UK (EPIC, first subjects) East Anglia[28]	CS information in PS study (baseline)	879 m/1089 w	44–75	FFQ 12 months (+repeated diary and 24 h)	25 F (frequency per day?)	5 clusters, 25 foods
C-8 Greenwood *et al* (2000) UK (Women's cohort study)[30]	CS	33971 w	35–69	FFQ 217 items, 12 months	74 (merged) F (10 frequency categories)	7 clusters, 74 foods
C-9 Pryer *et al* (2001) UK (DNSBA)[29]	CS (BMI measured after 7 day diet record)	1087 m/1110 w	16–64	Weighed 7day record	51 F (standardised)	4 of 8 clusters described by 25 foods/drinks

[a]Notes: *Setting*—SENECA, in Belgium, Denmark, France (×2), Italy, Netherlands, Portugal, Spain, Switzerland and Poland (not all included in both studies); *Design*—CS = cross-sectional, PS = prospective (follow-up), BMI = body mass index; *Gender*—m = men, w = women; *Diet method*—D-H = Diet history, FFQ = Food Frequency Questionnaire, 24 h = 24h recall. Reference period given if available; *Number of Input*—F = foods or food groups, N = nutrient-level data (protein, fat (subtypes), sugar, vitamins etc) or energy measures, S = serum levels of folic acid and B_{12}.

Cluster analyses. Nine studies were identified (Table 3). The variables (six to 74) entered in the analysis to segregate the clusters of subjects ranged between: relative energy contribution from an array of nutrients or nutrient-ratios.[25–27] standardised measures of food intake;[28,29] FFQ categories;[30] relative energy contribution by various foods;[31,32] or vitamin/mineral intake and status.[33] The variables were standardised in a number of different ways; (a) a zero mean/one unit variance; (b) by a weighed scoring system; (c) as proportion of food group energy or weight to total energy or weight (energy percentage or weight percentage) or (d) by ways not described. The clustering method used in the majority of studies was the iterative *k*-means clustering. Another method used was the hierarchical agglomerative clustering with Wards method of squared Euclidian distance[29] (see for example Aldenderfer and Blashfield[8]). A label based on the characteristic food intake was given to each cluster (Table 6).

Methods used to associate food intake patterns with obesity or BMI

The assessment of associations—between food intake patterns and BMI or obesity—was carried out differently in the three types of studies. In some studies a score based on the diet index or a factor score was correlated with BMI[11,22] or included in a linear regression analysis.[24,34–36] In other studies, subjects were categorised by for example quintiles of factor scores for each factor or index score in order to analyse for trends in BMI across categories,[6,16–19,21,23,37–41] frequency of obesity over categories[15,42] or, vice versa, factor score across categories of BMI.[43] Using cluster analysis, subjects belonging to each cluster were compared with respect to frequency of obesity,[27] waist–hip ratio[30] or mean BMI (all other cluster analysis studies).

Results

In Tables 4–6, the associations between food intake patterns and BMI or obesity are shown. '[I-1]' etc corresponds to the same numbers in Tables 1–3 and refers to diet index study 1 etc. The 10 studies in which no pattern was found to be significantly associated with BMI are shown separately in each of the three tables.

The index studies found that subjects having a high intake of 'high-energy/low-nutrient foods' [I-1], a low 'diet diversity' [I-3] or a high 'fat intake score' [I-7] were more likely to be obese/overweight. The 'variety index (higher vegetable variety)' [I-8] was negatively associated with body

Table 4 Diet index and body mass index/obesity[a]

References Table 1	*Diet indexes*	*Results*
I-1[15]	Type A foods: pasta/cereals/rice, starchy vegetables, bread, desserts, snack chips/crackers, soft drinks/lemonade, jams/jelly, table fats/salad dressings and gravy/sauces Type B foods: milk, meat/eggs/cheese, legumes, non-starchy vegetables, fruits and juices	The prevalence of obese[b] was higher (61% of men and 53% of women) in the group of subjects which had a higher intake of type A foods 'high energy/low nutrient' relative to type B foods 'protective/vitamin rich food groups'
I-3[20,39]	Diet diversity score (DDS): 1–5 1 pt each for presence of dairy, meat, fruit, grain and vegetables	The prevalence of subjects in the third tertile of BMI was lower with higher DDS
I-7[24]	Fat intake score (FIS): range 12–45 ($\geq$25, high fat intake/choice)	Subjects with a BMI $\geq$ 27.3 had an odds ratio of 2.4 of being in the high score group of FIS adj. for education (y), total blood cholesterol, smoking
I-8[22]	Var(sweet): 'variety of sweets, snacks, condiments, entrées, carbohydrates'	Var(sweet) adjusted for age and sex was positively associated with percentage body fat[c]
	Var(vegetables): 'Variety of vegetables' Variety ratio: between 'variety of vegetables' and 'Variety of sweets etc'	Var(vegetables) adjusted for age and sex and the variety ratio adjusted for age, sex and dietary fat was negatively associated with percentage body fat
I-11[17] I-12[18]	Healthy eating index = HEI = sum of scores (each 0–10) for dairy, meat, fruit, grain, vegetables, total fat, SFA, cholesterol, sodium and variety relative to recommendations	Mean BMI was lower in upper quintiles of HEI
	Studies in which the association between diet index and BMI was non significant[d]	
I-2[19]	Ten most prevalent combinations of $\pm$ dairy, meat, grain, fruit and vegetables (DMGFV)	Mean BMI did not differ between categories of DMGFV food combinations
I-4[11]	Healthy eating index (HEI) = sum of scores (0–10 each) for dairy, meat, fruit, grain, vegetables, total fat, SFA, cholesterol, sodium and variety relative to recommendations	Prevalence of BMI > 30 was equal over categories of HEI
I-5[23]	Four combinations of high- and low- fat and sugar: LF-LS, LF-HS, HF-HS and LF-LS, and quintiles of 'sugary fatty foods'	Mean BMI did not differ between categories. Adjusted for age, smoking, energy, fat intake and dieting/under-reporting Significant correlation between BMI and energy percentage extrinsic sugar = -0.1
I-6[21]	Total diet diversity (DD): total number of items reported proportion of red meat/fish/poultry/eggs; fruit; vegetables; whole grains; refined grains; dairy. In addition 'animal/plant food ratio'	Mean BMI, m: [kg/m^2], w: [kg/m$^{1.5}$] did not differ in subjects below and above median of DD score or animal/plant food ratio
I-9[6]	Recommended foods score (RFS): sum of 1–23 foods eaten $\geq$ 1/week including six fruit items, 10 vegetables, chicken/turkey, fish, dark bread, corn bread, high-fibre cereals, cooked cereals and low-fat milk	Baseline BMI did not differ by quartiles of RFS
I-10[16]	'Energy-dense, nutrient-poor foods' (EDNP): tertiles of percentage of daily energy in each and all of five EDNP groups (visible fat, sweeteners, desserts, salty snacks and miscellaneous)	Percentage BMI > 24.9 and percentage high waist circumference[e] did not differ over tertiles of energy percentage from EDNP adjusted for age, sex and race

Note: [a]Body mass index was measured as (kg/m^2) and entered in the analyses as a continuous variable unless otherwise stated. If a value or category is given; obese above that value were compared to non-obese. [b]Slender, sturdy, stocky, and obese by eye. [c]Body fat measured by hydrostatic weighting. [d]If $P > 0.05$ or 'non significant'. [e]Prevalence of high waist circumference (> 102 cm for men, > 88 cm for women).

fat (percentage of body weight) and subjects in the higher quintiles of the 'healthy eating index' [I-11], [I-12] had a lower mean BMI than subjects in the lower index categories.

For the studies using factor analysis the picture was more complex as there were more than one score. The foods loading the highest on each of the 'significant' factors have been listed in the notes below Table 5. To limit the amount of information, only the top three foods were included, as they represented each factor quite well.

Score in the 'low culinary complexity'(men only) and 'satiating' factor as well as total energy intake [F-1] was *negatively* associated with BMI, as was score in the 'convenience' factor [F-2]. In [F-3] score in 'traditional'(vegetables) was negatively associated with male BMI while score in 'salad' and 'high-fat' was positively associated with male BMI and 'fruit' with female BMI. Subjects in higher quartiles of 'bush food' score [F-6] had higher odds of being obese. BMI was lower with higher scores in the 'high fat-/sugar-dairy' factor [F-7 men] and 'drinker' factor [F-7 women] while BMI was higher with quintile of score in the 'Western' factor and for men in the upper quintiles of score in the 'drinker' and 'fruit juice' factors [F-7]. The last study [F-8] confirmed the positive trend for the 'Western' factor and also showed a negative trend for BMI with quintile of score in the 'prudent' factor, which could not be seen in the previous study [F-7].

The studies in which subjects were categorised by cluster analysis all presented mean values of BMI in each cluster as shown in Table 6 except for one [C-2], in which the percentage of obese in each cluster was given.

Table 5 Factor score and body mass index/obesity (m = men, w = women).

Refrences as in Table 2	Factors	Measure of outcome[a]	Results (see notes for details on factor loadings) High score in factor associated with lower BMI	higher BMI
F-1[34]	3 factors: *healthful; low culinary complexity; satiating*	BMI regressed on factor scores adjusted for age.[b]	*Low culinary complexity* (m)*/(w)[NS] *Satiating* (m)*/(w)**	
F-2[35]	4 Factors: *traditional; cosmopolitan; convenience; 'meat & two vegetables'*	BMI regressed on factor scores adjusted for age, socioeconomic group, marital status, religion, geography, smoking, and drinking	*Convenience* (m)[NS]/(w)*	
F-3[52]	9 factors: *whole grain; healthful; low cost; salad light; snacks; traditional; fruit; high fat*	BMI correlated with factor scores adjusted for age and education[c]	*Traditional* (m)*	*Fruit* (m)[NS]/(w)**High fat* (m)*/(w)[NS]*Salad* (m)*/(w)[NS]
F-6[42]	7 factors: *vegetables; junk foods; breakfast foods; hot meal foods; tea foods; 'bread & butter'; bush foods*	OR non-obese *vs* obese by quartiles of score in factor adjusted for age and sex[b]		*Bush foods** (OR of obesity higher in upper quartiles of score in factor)
F-7[37]	7 factors: *'substituter'; prudent; 'coffee & roll'; high fat/sugar-dairy; drinker; fruit juice; Western*	Trend in mean BMI[c,d] over quintiles of factor score	*High fat/sugar-dairy* (m)*/(w)[NS] *Drinker* (w)*	*Drinker* (m)* *Fruit Juice* (m) **Western* (m)*/(w)*
F-8[40]	2 factors: *prudent; Western*	Trend in mean BMI[c] over quintiles of factor score	*Prudent* (m)*	*Western* (m)*
	Studies in which the association between factor score and BMI was non significant			
F-4[36]	7 factors: *nutrient dense; traditional; transitional; nutrient dilute; protein rich; high-fat dairy; mixed dishes*	Adjusted for over sampling in HHANES (Duncans multiple means test and ANOVA used) [b]		
F-5[43]	3 factors: *high-energy density; traditional; health-conscious*	Pattern score difference in BMI categories. Adjusted for energy intake[b,c]		
F-9[41]	2 factors: *prudent; Western*	Trend in mean BMI over quintiles of factor score. Adjusted for age and energy[c]		

Notes: *$P<0.05$, **$P<0.001$, NS non-significant. [a]BMI (body mass index) was measured as (kg/m^2) and entered in the analyses as a continuous variable unless otherwise stated. [b]OR = odds ratio. Source of weight and height data not clearly stated. [c]Self-reported weight and height. [d]BMI m: (kg/m^2), w: (kg/m$^{1.5}$), [e]BMI < 20, 20–25, 25–27, > 27 (kg/m^2).
'Top 3' foods loading in patterns with significant differences/correlation: *low culinary complexity (F-1)*: — confectionery, butter, cookies. *satiating (F-1)*: — macaroni, sausage, white bread. *convenience (F-2)* — beer, chips, sauces. *traditional (F-3)* — wax beans, green beans, potatoes. *fruit (F-3)* — peaches, plums, pears. *high fat (F-3)* — eggs, bacon, sausage. *salad (F-3)* — lettuce, celery, green pepper. *bush food (F-6)* — rabbit, duck, fish. *high fat/sugar dairy (F-7)* — high sugar dairy foods, high fat dairy foods, yoghurt. *drinker (F-7w)* — wine, liquor, beer. *drinker (F-7m)* — wine, liquor, fish. *fruit-juice (F-7)* — fruit juice, high sugar drinks, canned fruit. *Western (F-7m)* — red meat, processed meat, eggs. *Western (F-7w)* — red meat, processed meat, fast food meats. *prudent (F-8)* — other-, greenleafy-, dark-yellow- and cruciferous vegetables. *Western (F-8)* — red meat, processed meat, refined grains.

A lower mean BMI was seen in clusters labelled: 'high alcohol/low nutrients' [C-1], 'meat and cheese' [C-6], 'skim milk' [C-6], 'low or high diversity vegetarians' [C-8],'convenience' [C-9w] and 'mixed/sweet' [C-9m]. A higher BMI was seen in clusters labelled: 'high fat/low alcohol' [C-2], 'meat/potatoes', 'bread/potatoes' [C-3], 'soft-drinks' [C-6] and 'traditional' (British diet) [C-9]. Men and women in the 'fruit/vegetables/poultry/fish' and 'low-calorie' cluster and men in the 'alcohol/nuts/low cereal/meat' cluster had a higher BMI than men and women respectively in the remaining clusters [C-7].

Summary of results

Men and women had similar food intake patterns, but in women the patterns were less often positively associated with BMI or obesity. Not all studies, however, provided information on gender differences with respect to food intake patterns (see Tables 4–6).

The relation between intake of high-fat foods, broadly defined, and obesity, addressed in cross-sectional studies of nutrients reviewed by Lissner and Heitmann,[2] was supported by 10 of the food intake pattern studies [I-1], [I-7], [I-8], [I-11], [I-12], [F-3m], [F-7], [F-8], [C-2] and [C-9]. Four other studies found an *inverse* association between energy-dense (eg high-fat) foods and BMI [F-1], [F-2w], [C-6], [C-7], while one study observed a high-fat/sugar dairy factor associated with lower BMI and a 'Western' factor (with many high-fat foods) associated with higher BMI [F-7].

Discussion

We have reviewed 30 published studies for associations between food intake pattern and BMI or obesity and found no evidence of a clear-cut relationship. Studies associating food intake patterns with BMI were included as well as studies associating patterns with obesity. Whether a higher mean BMI in general is equivalent to a higher prevalence of

Table 6 Body mass index/obesity by cluster (m = men/w = women)

Refrences as in Table 3	*Clusters*	*Measures of outcome*	*Results*	
			Mean BMI lower in	*Mean BMI higher in*
C-1[25]	4 clusters (m): *high alcohol/low nutrients; meat/fish/cheese/olive-oil; vegetables/starchy foods; seed oil/ fruit/cake*	Mean BMI at entry to study	*High alcohol/low nutrients* (m)*	
C-2[27]	3 clusters (m + w): *high fat/high alcohol; medium fat/low alcohol; high fat/low alcohol*	BMI ≥ 30 (%), adjusted for smoking, breakfast habits, special diet, supplement use, alcohol, coffee		*high fat/low alcohol** (higher prevalence of BMI ≥ 30)
C-3[31]	4 clusters (m + w): *alcohol; milk/cereal; meat/potatoes; bread/potatoes*	Mean BMI, adjusted for age and gender		*Meat/potatoes* Bread/potatoes**
C-6[32]	6 clusters (m + w): *meat and cheese; skim milk; pastry; meat; white bread; soft drinks*	Mean BMI, adjusted for age, gender, substudy, exercise, cholesterol	*Meat and cheese* (m)* *Skim milk* (m)*	*Soft drinks* (m)*
C-7[28]	5 clusters (m + w): *vegetarian/low meat/cereal/legume/fruit/younger; red meat/potatoes/sweet foods/cakes/ tea/older males; alcohol/nuts/low cereal/ meat/younger males; fruit/vegetables/ poultry/fish/MUFA/PUFA/females; low calorie/females*	Mean BMI, adjusted for age		*Alcohol/nuts, etc* (m)* *Fruit/ vegetables, etc* (m)*/(w)* *Low calorie/females* (m)*/(w)*
C-8[30]	7 clusters (w): *low diversity vegetarian; high diversity vegetarian; health conscious; monotonous low-quantity omnivores; conservative omnivores; traditional meat/ chips/pudding; higher diversity traditional omnivores*	Mean BMI/WHR	*Low diversity vegetarian* (w)* *High diversity vegetarian* (w)*	
C-9[29]	7 clusters (4m + 4w): *beer/convenience* (m); *convenience* (w); *healthier/cosmopolitan* (w); *mixed/sweet* (m); *healthier/sweet* (w); *healthier* (m); *traditional* (m/w)	Mean BMI, ANOVA for men and women separately*	*Mixed/sweet* (m) *Convenience* (w)	*Traditional* (m/w)
	Studies in which the association between cluster membership and BMI was non significant			
C-4[26]	3 clusters (m): *healthy; refined sugars; meat; alcohol,*	Mean BMI, *P* after adjustment for age, social ecnomic status SES, smoking and being on a prescribed diet		
C-5[33]	4 clusters (3m + 4w): *small eaters; lean/green; gourmands; modest eaters (w); milk drinker*	Mean BMI at follow-up		

Notes:* Significantly ($P < 0.05$) different from clusters not listed under results, BMI (body mass index) measured as (kg/m^2), WHR = waist circumference/hip circumference.
MUFA = monounsaturated fatty acid rich foods, PUFA = polyunsaturated fatty acid rich foods.

obesity in a given subgroup is questionable. However, a comparison between different populations showed an increased skewness (ie more obese than expected in a normal distribution) in populations in which mean BMI was high.[44]

In the light of current beliefs on food-based dietary recommendations — cutting down on fatty foods, eating more vegetables and drinking less alcohol — the results emerging from our review were rather mixed with regard to preventing unintentional weight gain. Seven studies (of which five were diet index studies) were in agreement with the recommendations. That is, a high score on a recommended food intake pattern was associated with a lower BMI or a lower prevalence of obesity. Four studies showed opposite associations, 11 studies did not have significant results while two studies internally had somewhat contradictory results.[29,37]

The fact that the loadings on factors and characteristics of clusters, respectively, showed some between-study similarities with regard to food intake patterns, suggests a reasonably good consistency of the factor and cluster analysis method. This could, however, to some extent be a consequence of the subjective choices made at various steps in the analyses. Preconceived opinion could thus lead to ruling out unlikely factors or clusters in preliminary analyses. A strong similarity could be seen between the score on a 'prudent' diet factor and the 'healthy eating index' study with regard to association with BMI over quintiles when used in the same population (the Health Professionals cohort I-11, F-8).[40] Some similarity also existed between the findings of two studies in which the Dietary and Nutritional Survey of British Adults (DNSBA) was used. In the diet index study,[23] percentage of energy from 'sugary fatty foods' was negatively correlated with BMI and in the cluster analysis,[29] a cluster labelled 'mixed/sweet' had the lowest mean BMI of the four male clusters (while the pattern for women was less alike).

Limitations of pattern analysis on food intake data

The diet index method or similar *a priori* approaches are confirmatory by nature, and they add little, in terms of food intake pattern exploration, to the knowledge behind the defined index. The cut-off points of the variables included in the diet index are often rather arbitrary or based on median values (or similar) in the data, and hence, do not necessarily have a plausible biological basis with respect to obesity development. This is, of course, not often different for other methods, but due to the assumed synergistic effect of the index variables there is a need for defining proper cut-off points for each variable. A major reason for making an index, rather than studying its component variables in isolation, is to study a combined effect of the variables. Further, one of the variables may have a major influence on the outcome, and the index's predictive value may therefore reflect the correlation with a single influential variable.

If no well justified '*a priori*' hypotheses relating food intake pattern to health can be prepared, as may be the case for the diet–obesity relation, the research in food intake patterns can only provide explorative results at present.

The exploratory factor analysis method has some general limitations. For instance, the exact definition of a 'factor' and the individual 'factor score' may prove difficult in readily understandable terms. The relevant possible combinations of variable scores with factor loadings into a high factor score may not be equally hazardous/healthy for the individual. The method involves a large amount of data driven and subjective decision-making in the course of the analysis (variable scale, number of variables, number of factors, rotation method, interpretation, criteria for interpretation etc.), which may contribute to the inconsistency and considerably limit the ability to generalise the results.

The cluster analysis method also has its limitations. First, there is no gold standard for determining the number of clusters. Second, the dietary input needs to be considered carefully in terms of scaling, since the differences between high, moderate or low intake are central to the analysis. Typical scenarios are: (a) a few distinct clusters with very few people and one or more large left over cluster(s); or (b) more similarly sized clusters with a minimum of inter-cluster variation in diet intake. Another problem is the within-cluster range, which is often wide and might even contain a null intake of (one or more of) the foods chosen to identify the cluster.

Limitations in studies on food intake pattern and obesity

The apparent lack of consistency of associations between diet pattern and BMI or obesity prevalence within as well as between studies using different methods of analyses, as evidenced by the contradictory findings, suggests that the concept of using food intake patterns rather than single nutrient approach may not be useful. A study, not included due to the design (BMI was not used as a dependent variable), had BMI as one of the indicators along with lifestyle and diet within the exploratory factor analysis, and the result was a factor loading primarily on BMI.[45] One would expect high loadings of such diet indicators on the 'body mass factor', if BMI had been highly correlated to some of the diet indicators, but this was not the case.

A number of limitations apply such as: (a) diet under-reporting; (b) the cross-sectional measurement of food intake and BMI; (c) confounding by age, gender, physical activity, smoking or other behaviours; (d) misclassification by proxy measures of obesity; and (e) factors/clusters not derived on the basis of association with obesity.

Diet under-reporting is a well-known phenomenon in epidemiological studies, especially when a differential under-reporting by obese people (shown by energy balance estimations) lead to a biased food intake assessment.[46] The problem of diet under-reporting is relevant to pattern analysis, as a bias in the reporting of for instance foods high in fat or sugar will be reflected in a low score in indexes, factor(s) or less distinct cluster characteristics. For instance, the finding that energy intake was negatively associated with BMI may be ascribed to under-reporting bias in addition to the effect of decreased physical activity and reduced thermo genetic response among obese.[34] Under-reporting of fat is necessarily reflected in an under-reporting of foods high in fat or a corresponding over-reporting of foods low in fat, ie vegetables. In an analysis of data from the 1990 Ontario Health Survey, potential under-reporters, defined by an energy intake less than 1.2 times BMR (intake measured by FFQ and BMR estimated by equations), reported a diet more compatible with current dietary guidelines: lower intakes of fat and desserts and higher intake of fruits and vegetables.[47]

Equally, the most healthy clusters in the DNSBA study, 'healthier' and 'healthier/cosmopolitan' had 39.3 and 48.7% low energy reporters respectively for men and women.[29] However, FFQs especially seem prone to over-reporting of vegetables when compared to diet records as the gold standard. Despite this apparent reporting error, Hu *et al* found the food intake factors ('Western' and 'prudent'), extracted from FFQ data, to be reasonably comparable with two factors extracted from diet records.[48] In spite of the sensitivity to capture food intake patterns, the use of factor analysis (or other scoring methods) is no safeguard against misclassification due to false information.

Simultaneous measurements of diet and BMI (cross-sectional study design) made in all the studies reviewed do not allow conclusions suggesting causal direction or about individual diet pattern and change in BMI. Additionally, only four studies inquired whether subjects were on a (prescribed) diet, and excluded dieters or controlled for it in the analyses (stepwise exclusion;[23] exclusion[27] or adjustment[26]). Hence, the obese subjects may have had a diet appropriate for intended weight loss at the time their diet was assessed, but a different less healthy diet in the years of fat accumulation. The diet history and FFQ methods normally refer to a reference period (see Table 1–3)—typically 6 or 12 months—that the FFQ is designed to cover. However, replies given are still vulnerable to poor or biased recall and they may well be affected by the current nutritional or anthropometric status and by social desirability of the diet pattern or the body image.[49]

Slattery *et al*[37] found an association of physical activity with the 'prudent' pattern and smoking with the 'drinker' pattern, respectively. In other studies, the physically active showed the same tendency to score high on a prudent food intake pattern.[6,17,18,40] Food intake patterns appeared to be more weakly associated with BMI or obesity in women, as illustrated by the two studies in comparable cohorts by McCullough *et al*,[18,17] in which the difference between mean BMI of subjects, categorised by the lowest and the highest quintiles of score on the 'healthy eating index' (HEI), was 1.1 kg/m^2 (24.9–26.0) for men, but only 0.7 kg/m^2 (24.5–25.2) for women. A high score on the HEI was likewise inversely and weakly related to the risk of coronary heart disease for men, but not for women, controlled for BMI and other variables. These findings raise the question about the need for controlling for covariates such as total energy intake, gender, physical activity, smoking, parity or other causes of hormonal changes (in women), in studies with BMI as the outcome. This was done in some but not in all studies, probably as a result, of focusing on other outcomes than obesity. Whether or not the analysis should be adjusted for these covariates depend on their status in the presumed causal model. A potentially intriguing covariate is the genetic predisposition with which there may be an interaction.[50]

Healthy eating (as defined by the various scoring methods) seems to be part of an overall healthier lifestyle, in which the relative importance of each practice can be difficult to determine. An example of such a healthy behaviour was found in a study using factor analysis based on multiple behavioural indicators including some related to diet on a Dutch cohort of young adults.[51] The behaviours 'choice of bread' (fibre), 'fruit consumption' (many), (not) 'omitting breakfast' and 'walking/cycling most days' were indicators of a behaviour labelled 'health conscious', which had a significant negative association with BMI adjusted for age and level of education in both men and women.

BMI is a proxy measure of obesity only and using it instead of measures of body composition (eg percentage body fat), or body fat distribution (eg waist circumference or waist–hip ratio), may result in misclassification. For instance, mortality was linearly associated to the ratio between fat-free body mass and body fat-mass, whereas BMI was associated with mortality in a U-shaped relation.[52]

These limitations could possibly explain some of the discrepancy between the results.

Conclusion

Eleven of the 30 studies did not show any significant relation between food intake patterns and BMI, and the associations in the remainders of the studies were inconsistent. There were, however, traces of evidence that a food intake indicated by a high score on predefined indices designed to identify a varied diet high in fruit and vegetables, and low in meat and fat, was associated with a lower BMI. The heterogeneity of the studies made the comparison and hence the interpretation difficult, and the lack of studies designed to measure weight *changes* in relation to food intake pattern limits the impact of these studies in this context. Thus, more research is needed to particularly explore a possible association of food intake patterns with the development of obesity.

Furthermore, if attempts are made to explore causal associations between diet factor scores and disease, the *a priori* knowledge of the outcome should influence the other elements of the study (ie relevant confounder and interaction control) and the time-relationship between dietary exposure and subsequent outcome should be taken into account. A more confirmative approach may be the use of the structural equations modelling technique and the confirmative factor analysis, which allows for hypothesis testing of predefined relations between foods, food intake pattern, covariates and an outcome in one model as generated from other studies or from analysis of split samples within the same study.

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