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Anti-inflammatory Dietary Inflammatory Index scores are associated with healthier scores on other dietary indices

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Abstract

Dietary components are important determinants of systemic inflammation; a risk factor for most chronic diseases. The Dietary Inflammatory Index (DII) was developed to assess dietary inflammatory potential. It was hypothesized that anti-inflammatory DII scores would be associated with ‘healthier’ scores on other dietary indices. The Energy Balance Study is an observational study focusing on energy intake and expenditure in young adults; only baseline data were used for this analysis (n=430). The DII, as well as the Healthy Eating Index-2010 (HEI-2010), the Alternative Healthy Eating Index (AHEI), and the Dietary Approaches to Stop Hypertension Index (DASH) were calculated based on one to three 24-hour dietary recalls. General linear models were used to estimate least square means of the AHEI, HEI-2010, and DASH according to DII quartiles. Those with higher (i.e., more pro-inflammatory) DII scores

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Conflicts of Interest

Dr. Hébert owns controlling interest in Connecting Health Innovations LLC (CHI), a company planning to license the right to his invention of the dietary inflammatory index (DII) from the University of South Carolina in order to develop computer and smart phone applications for patient counseling and dietary intervention in clinical settings. Drs. Michael Wirth and Nitin Shivappa are employees of CHI. Steven N. Blair has served on the scientific advisory boards of Technogym, Clarity, Cancer Foundation for Life, and Santech. He has received research funding from BodyMedia, Technogym, The Coca-Cola Company, the U.S. Department of Defense, and the National Institutes of Health. He receives book royalties from Human Kinetics.

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were more likely to be males, have less than a completed college education, and be younger. Additionally, those with higher scores for cognitive restraint for eating or drive for thinness had lower (i.e., anti-inflammatory) DII scores. Linear regression analyses indicated that as the DII increased, the AHEI, HEI-2010, and DASH dietary indices decreased (i.e., became more unhealthy, all $p < 0.01$). The DII is a novel tool that characterizes the inflammatory potential of diet and is grounded in the peer-reviewed literature on diet and inflammation. Findings from the Energy Balance Study indicate that the DII is associated with other dietary indices, but has the added advantage of specifically measuring dietary inflammatory potential, a risk factor for chronic disease.

Keywords

Dietary Inflammatory Index; observational; inflammation; diet; chronic disease

1. Introduction

Diet is a strong moderator of chronic, systemic inflammation [1]. For example, ‘unhealthy’ dietary patterns (e.g., Western-style diets high in fats, refined carbohydrates, protein) are typically associated with higher levels of inflammation, whereas ‘healthier’ diets (e.g., Mediterranean diets high in fruits, vegetables, fish) are associated with lower levels of inflammation [1]. This is disconcerting considering that chronic inflammation, which can occur as a result of repeated injuries or stressors on the body, including poor diet, is associated with most major chronic disorders (e.g., cardiovascular disease [CVD], cancer, diabetes) [2, 3].

Typically, dietary quality indices are based on *a priori* dietary guideline definitions (e.g., Healthy Eating Index) [3]. The Dietary Inflammatory Index (DII) is a relatively new dietary index that is based on peer-reviewed research focusing on diet and inflammation and is standardized to world average dietary intake [4]. The DII was validated against inflammatory biomarkers in previous research [5–7]. The DII also has been associated with other outcomes including, but not limited to, cancer, anthropometric measures, and asthma [8–10]. Based on the fact that healthier diets incorporate many foods that contain anti-inflammatory constituents, it is not surprising that more anti-inflammatory DII scores were observed with various types of vegetarian diets in a randomized control trial (RCT), [11] or with ‘healthier’ diets in a simulation analysis compared to a fast food diet [12].

However, to date, no DII analysis has examined the relationship between the DII and other established and commonly used dietary indices such as the Healthy Eating Index-2010 (HEI-2010), the Alternative Healthy Eating Index (AHEI), and the Dietary Approaches to Stop Hypertension (DASH) [13–15]. Therefore, this analysis addressed the hypothesis that more anti-inflammatory (i.e., lower) DII scores would be associated with ‘healthier’ (i.e., higher) scores on the HEI-2010, AHEI, and DASH indices using data collected from the Energy Balance observational study (University of South Carolina, Columbia, SC), including 24-hour recalls (24HR) [16].

2. Methods and Materials

2.1 Study Design

The Energy Balance Study, which is a prospective cohort (follow-up visits occurred every 3 months), was designed to examine the impact of energy expenditure and intake on changes in body habitus in 430 young adults. Methodology for the Energy Balance Study has been described elsewhere [16]. In short, eligible participants were between 21 and 35 years of age, had a BMI of 20–35 kg/m², and lived in or near Columbia, South Carolina. Exclusions were applied at recruitment and included major acute or chronic health conditions, plans to move out of the study area within the first year of follow-up, or large changes in body composition prior to the study start date. Only baseline data were utilized for this cross-sectional analysis. The Energy Balance Study was approved by the Institutional Review Board of the University of South Carolina and all participants provided written informed consent.

2.2 Dietary Data Collection and Indices

Dietary information was collected by telephone-administered 24HRs over a 14-day period. The Nutrient Data System for Research (version 2012, Nutrition Coordinating Center, University of Minnesota, Minneapolis, Minnesota) was used to estimate average energy, nutrient, and individual food intakes from the 24HR. Dietary data from the 24HRs was used to calculate the HEI-2010, AHEI, DASH and DII. The HEI-2010, AHEI, and DASH were created and scored in accordance with previous scoring guidelines [13–15].

The HEI-2010 was updated compared to the HEI-2005 based on recommendations in the 2010 Dietary Guidelines released by the United States Department of Agriculture. The HEI-2010 is made up of 9 adequacy components (total fruit, whole fruit, total vegetables, greens and beans, whole grains, dairy, total protein foods, seafood and plant proteins, and fatty acids) and 3 moderation components (refined grains, sodium, and empty calories). Each component has standards for maximum scores and scores of zero. Values falling between zero and the maximum are scored proportionally [14]. The AHEI is composed of 9 components including servings of vegetables, fruits, nuts and soy protein, and alcohol; ratio of white to red meat; cereal fiber grams; percent of energy from trans-fat; ratio of polyunsaturated to saturated fat; and duration of multivitamin use. All components are proportionally scored on a scale of 0 to 10 based on minimum and maximum criteria [15]. It should be noted that duration of multivitamin use was not available within Energy Balance; therefore, this component was based on a ‘yes/no’ response with 7.5 points for yes and 2.5 points for no. DASH index scores were calculated based on quintiles (scored 1–5) of servings per day for fruits, vegetables, nuts and legumes, whole grains, low-fat dairy, sodium, red and processed meats, and sweetened beverages; values were summed across these 8 components with sodium, meats, and sweetened beverages being scored in reverse order [13]. Higher HEI-2010 (range: 0–100), AHEI (range: 2.5–97.5), and DASH (range: 8–40) scores indicate ‘healthier’ diets.

Inflammatory effect scores derived from data reported in 1,943 research articles examining the relationship between various dietary constituents (referred to as food parameters) and

inflammation (interleukin [IL]-1 β , IL-4, IL-6, IL-10, tumor necrosis factor- α and c-reactive protein) became the basis for the DII. Exposure estimates were scored relative to a “world” database (based on 11 populations from around the world including the United States, the United Kingdom, Bahrain, Mexico, Australia, South Korea, Taiwan, India, New Zealand, Japan, and Denmark) which consists of means and standard deviations for DII food parameters. The DII food parameters used to calculate DII scores within the Energy Balance study included: carbohydrates; protein; fat; alcohol, fiber; cholesterol; saturated, monounsaturated, and polyunsaturated fatty acids; omega 3 and 6 fatty acids; trans-fat; niacin; thiamin; riboflavin; vitamins A, B6, B12, C, D, and E; iron; magnesium; zinc; selenium; folate; beta-carotene; anthocyanidins; flavan-3-ols; flavones; flavonols; flavonones; isoflavones; caffeine; garlic; ginger; onions; saffron; turmeric; pepper; thyme or oregano; rosemary; and tea. World means were subtracted from the actual intake and divided by its standard deviation, creating a z-score. These were converted to percentiles to control for skewing and were centered on 0 by doubling the percentiles and subtracting 1.0. These centered scores were then multiplied by the inflammatory effect scores and then summed across all food parameters. More details on DII calculation can be found elsewhere [4]. Higher scores are more pro-inflammatory and lower scores are anti-inflammatory (theoretically maximum range: -8.87 to 7.98). DII scores were calculated per 1,000 calories consumed to account for inter-individual differences in energy intakes.

2.3 Covariate Information

Potential covariates for adjustment included body mass index (BMI=weight(kg)/height(m)²), percent body fat (from dual x-ray absorptiometry), waist-to-hip ratio (WHR), demographic, and health habit information (e.g., age, sex, race, education, income, employment, marital status, smoking status). In addition, psychosocial measures (e.g., social approval and desirability, Perceived Stress Scale [17], Eating Disorder Inventory [EDI] [18], Three-Factor Eating Questionnaire [TFEQ] [19]) were included. The EDI measures various behavioral and psychological traits associated with anorexia nervosa and bulimia [18]. The TFEQ measures three dimensions of eating behavior including cognitive restraint of eating, disinhibition, and hunger [19]. Physical activity (i.e., total light, moderate, and vigorous physical activity, as well as steps) and sleep estimates were obtained through BodyMedia's SenseWear Mini[®] physical activity monitor [16]. On average, participants wore the armband for 9.8 $\pm$ 0.9 days for 23.2 $\pm$ 0.8 hours/day.

2.4 Statistical Analyses

All analyses were performed using SAS[®] (version 9.3, Cary, NC). Population characteristics were compared across DII quartiles using chi-squares for categorical measures or trend tests for continuous measures. Pearson correlations were performed for the DII, HEI-2010, AHEI, and DASH using the scores as continuous variables. Variable selections began as a series of bivariate analyses (i.e., exposure + potential covariate) where covariates with a p-value 0.20 were added to a ‘full’ model. Backward confounder selections produced ‘final’ models that included all covariates that were statistically significant (p<0.05); covariates that changed the beta coefficient of the exposure by 10% also were retained. Least square means and 95% CIs of the HEI-2010, AHEI, and DASH were calculated among quartiles of

the DII using general linear models. Considering diet can differ according to sex, all analyses were stratified by sex.

3. Results

Among all participants (males: $n=212$, females: $n=218$), the average age was 27.7 ± 3.8 years, BMI was 25.4 ± 3.8 kg/m², and total physical activity hours per day was 5.9 ± 1.5 hours with an average of 7661 ± 2738 steps per day. Most subjects completed college (84%), had an income <\$60,000 (72%), and were European-American (67%). Those in DII quartile 4 (i.e., more pro-inflammatory) compared to quartile 1 were more likely to be male (59% vs. 38%, $p=0.01$), have less than a completed college education (27% vs. 9%, $p<0.01$), and have children (24% vs. 11%, $p=0.03$). Significant trends were observed for age (increased across DII quartiles, $p=0.01$), WHR (increased across DII quartiles, $p=0.04$), and cognitive restraint for eating (decreased across DII quartiles, $p<0.01$) (Table 1).

The DII was negatively correlated with the HEI-2010 ($r=-0.65$, $p<0.01$), AHEI ($r=-0.55$, $p<0.01$), and the DASH ($r=-0.52$, $p<0.01$) (data not tabulated). As hypothesized, compared to DII quartile 4, those in DII quartile 1 had healthier scores for the HEI-2010 (66.2 vs. 48.2, $p<0.01$), AHEI (53.8 vs. 39.0, $p<0.01$), and DASH (25.5 vs. 19.9, $p<0.01$) after adjustment for a variety of factors (see footnotes of Table 2 for list of adjustments). Statistically significant ($p<0.01$) linear associations also were observed between continuous DII scores and each of the dietary indices presented above (data not tabulated). Trend tests also were statistically significant ($p<0.01$ for all models). After further stratification by sex, the results appeared to be consistent among the male and female subgroups and mirrored results observed among all subjects (Table 2).

4. Discussion

This study accepted the hypothesis by finding that more anti-inflammatory DII scores (i.e., more negative) were associated with 'healthier' values on the HEI-2010, AHEI, and DASH indices. All four dietary indices take into account the complexity of diet as a whole. Use of dietary indices considers the fact that foods are eaten in combination and obviates the limitation that single nutrients may not reflect the overall quality of the diet. Additionally, single nutrients may be highly correlated and it may not be possible to separate out individual effects, or the effect of any single nutrient may be too small to observe. Lastly, examining a large number of individual food constituents may lead to chance findings [20]. The DII was derived from peer-reviewed literature by examining the relationship between dietary factors and inflammation to determine the inflammatory potential of diet which is a major risk factor for many chronic diseases. Although, the DII is distinctly different in its nature compared to these other dietary indices in what it represents and how it is scored, there is a good level of agreement between all indices.

Findings from this study are consistent with those from an RCT designed to test the effect of dietary regimens that differ in terms of food group and nutrient intake (participants were randomized into vegan, vegetarian, pesco-vegetarian, semi-vegetarian, and omnivorous diets). Compared to baseline DII values, DII values after that 2-month intervention were lower (i.e., more anti-inflammatory) for the vegan (mean DII: 0.3 vs. -1.2), vegetarian

(mean DII: 0.4 vs. -1.0), and pesco-vegetarian (0.9 vs. -0.7) diets [11]. In a simulation analysis of fast-food, Mediterranean, and macrobiotic diets, the DII was +4.0 for the fast food diet, -4.0 for the Mediterranean diet, and -5.5 for the macrobiotic diet [12].

In addition to the main findings, there were some notable findings relating the DII to various sociodemographic or psychosocial constructs. Females, participants with more education (4+ years of college), and those who were older had more anti-inflammatory diets. Two US studies, utilizing the HEI-2005, also indicated better dietary quality among females, those who were older, and those with more education [21, 22]. Additionally, in an analysis of diet quality from 187 countries, females and those who were older had better dietary quality [23]. However, it should be noted that the age range in the current study was relatively narrow and nearly all participants had at least some college education; direct comparison to these other studies may not be entirely appropriate.

Individuals with lower WHR had statistically significantly lower DII values. Not surprisingly, diet quality tends to be 'healthier' among those with lower body weights or BMI [24]. It is interesting to note that WHR is a measure of intra-abdominal adiposity, a factor strongly associated with inflammation [25]; the basis of the DII. Lastly, lower DII scores were associated with higher values for the Drive for Thinness subscale (i.e., concern with dieting, weight and fear of weight gain) of the EDI and the Cognitive Restraint subscale (i.e., ability to limit intake and achieve weight loss or control) of the TFEQ. Conceptually, these findings make logical sense; those who have more control over their eating or are actively trying to lose weight will tend to consume less energy-dense 'unhealthy' foods and/or more anti-inflammatory foods (e.g., fruits and vegetables).

This analysis was subject to a couple of limitations. For one, the study population was primary young, European-American, and highly active; thus results may not be generalizable to other populations. These indices were based on 24HR data and the composition of some of the subcomponents of each index may differ compared to other studies utilizing different dietary assessment methods. Additionally, as with other dietary reporting tools, the 24HR is subject to reporting bias, as it is based on self-report. Despite the limitations, this analysis made use of a wide range of covariate information available for confounder selection, including measures such as social desirability and approval which have been shown to bias dietary self-reports [26]. The 24HR is subject to less error than structured questionnaires [27] and its use allowed for inclusion of most of the food parameters comprising the DII; this is often times not the case with food frequency questionnaires. Also, 97% of subjects underwent at least two 24HRs, which contributes to the overall stability of the estimates [28].

In conclusion, this analysis showed that more anti-inflammatory DII scores are associated with healthier scores on several widely used dietary indices. However, the agreement between the DII and the other indices was around 0.55, which is good, but nowhere near perfect. Clearly, the DII accounts for different sources of variability, presumably related to inflammation, providing additional valuable information beyond other commonly used dietary indices. The DII was found to have good agreement with other dietary indices, and may have the added benefit of capturing information on a particular aspect of diet (i.e.,

inflammatory potential) that is directly relevant to the development of many chronic diseases [29] include cancer and CVD [3]. As it relates to human nutrition and health, the DII may serve as a useful tool that helps individuals choose more anti-inflammatory foods and meals which has the added benefit of helping individuals lower chronic inflammation, and in turn, chronic inflammatory-related disease risk or recurrence.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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Abbreviations

DII	Dietary Inflammatory Index
HEI-2010	Healthy Eating Index-2010
AHEI	Alternative Healthy Eating Index
DASH	Dietary Approaches to Stop Hypertension
CVD	cardiovascular disease
RCT	randomized control trial
IL	interleukin
WHR	waist-to-hip ratio
BMI	body mass index
EDI	Eating Disorder Inventory
TFEQ	Three-Factor Eating Questionnaire

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Table 1

Population characteristics by Dietary Inflammatory Index quartiles

Characteristic	DII Quartile 1	DII Quartile 2	DII Quartile 3	DII Quartile 4	p-value
Gender					0.01
Male	40 (38%)	50 (46%)	57 (53%)	63 (59%)	
Female	66 (62%)	58 (54%)	50 (47%)	43 (41%)	
Race					0.13
European-American	78 (74%)	75 (69%)	71 (66%)	60 (57%)	
African-American	8 (8%)	9 (8%)	16 (15%)	21 (20%)	
Asian	11 (10%)	12 (11%)	8 (7%)	15 (14%)	
Other	9 (8%)	12 (11%)	12 (11%)	10 (9%)	
Income (in Dollars)					0.61
0 – 19,999	18 (17%)	18 (17%)	16 (15%)	19 (18%)	
20,000 – 39,999	32 (30%)	34 (32%)	44 (41%)	38 (36%)	
40,000 – 59,999	21 (20%)	25 (23%)	20 (19%)	19 (18%)	
60,000 – 79,999	12 (11%)	10 (9%)	13 (12%)	18 (17%)	
80,000+	22 (21%)	20 (19%)	14 (13%)	12 (11%)	
Education					<0.01
<3 years of college	10 (9%)	19 (18%)	12 (11%)	29 (27%)	
4+ years of college	96 (91%)	89 (82%)	95 (89%)	77 (73%)	
Children					0.03
Yes	12 (11%)	12 (12%)	14 (13%)	25 (24%)	
No	94 (89%)	96 (89%)	92 (87%)	81 (76%)	
Currently Dieting					0.07
Yes	24 (23%)	31 (29%)	21 (20%)	15 (14%)	
No	82 (77%)	77 (71%)	85 (80%)	91 (86%)	
Smoking Status					0.46
Current/Former	23 (22%)	28 (26%)	24 (22%)	32 (30%)	
Never	83 (78%)	80 (74%)	83 (78%)	74 (70%)	
Continuous Measures					

Characteristic	DII Quartile 1	DII Quartile 2	DII Quartile 3	DII Quartile 4	p-value
Age (years)	27.8 ± 3.7	27.4 ± 3.6	27.1 ± 3.7	26.5 ± 4.1	0.01
Social Approval score	51.0 ± 8.4	51.5 ± 9.8	50.5 ± 9.4	52.9 ± 9.5	0.26
Drive for thinness ^{a,d}	4.0 ± 4.6	3.3 ± 4.4	2.9 ± 4.0	3.0 ± 4.4	0.07
Cognitive restraint ^b	12.4 ± 4.6	10.5 ± 4.5	9.8 ± 4.4	8.4 ± 5.2	<0.01
Physical Activity Hours ^c	5.9 ± 1.5	5.9 ± 1.5	5.8 ± 1.5	5.9 ± 1.5	0.86
Steps	7920 ± 3040	7536 ± 2173	7492 ± 2846	7700 ± 2839	0.53
Body mass index (kg/m ²)	25.1 ± 3.8	25.4 ± 3.4	25.7 ± 3.8	25.4 ± 4.3	0.58
Body Fat Percent	29.1 ± 8.8	28.4 ± 9.4	28.9 ± 9.4	27.6 ± 8.4	0.27
Waist-to-hip ratio	0.78 ± 0.07	0.79 ± 0.07	0.79 ± 0.07	0.80 ± 0.07	0.04

Column percentages not equaling 100% are due to rounding. Column totals not equaling total sample size are due to missing data. P-values for categorical variables were based on chi-square tests and p-values for continuous measures were based on trend test using general linear models. DII Quartile Ranges: 1 = -4.93 to -0.90 (n=106); 2 = -0.89 to 1.02 (n=108); 3 = 1.03 to 2.50 (n=107); 4 = 2.51 to 6.23 (n=106).

^a Subscale of the Eating Disorder Inventory = higher scores indicate a greater drive for thinness.

^b Subscale of the Three-Factor Eating Questionnaire = higher score indicates greater cognitive restraint.

^c Average daily hours of all (i.e., light to vigorous physical activity).

^d Statistically significant difference (p<0.05) between DII quartiles 1 and 4 using t-tests.

Table 2

HEI-2010, AHEI, and DASH by quartiles of the Dietary Inflammatory Index among all subjects and stratified by sex

Dietary Indices	All Subjects				
	DII Quartile 1	DII Quartile 2	DII Quartile 3	DII Quartile 4	p: 1 vs. 4
HEI-2010	66.2 (63.6–68.8)	59.6 (57.2–62.0)	55.3 (52.8–57.8)	48.2 (45.9–50.5)	<0.01
AHEI	53.8 (51.2–56.5)	50.1 (47.7–52.5)	45.3 (42.8–47.8)	39.0 (36.7–41.3)	<0.01
DASH	25.5 (24.4–26.6)	22.9 (21.8–23.9)	21.7 (20.6–22.7)	19.9 (18.9–20.9)	<0.01
Males					
HEI-2010	64.2 (60.3–68.1)	60.3 (56.7–64.0)	54.9 (51.6–58.3)	47.0 (43.9–50.2)	<0.01
AHEI	52.3 (48.4–56.2)	50.8 (47.1–54.4)	45.6 (42.3–49.0)	37.0 (33.8–40.2)	<0.01
DASH	25.7 (24.0–27.4)	23.3 (21.8–24.9)	22.1 (20.7–23.5)	19.9 (18.6–21.3)	<0.01
Females					
HEI-2010	67.5 (64.2–70.7)	58.8 (55.6–62.1)	55.7 (52.1–59.2)	49.7 (46.3–53.0)	<0.01
AHEI	54.7 (51.5–57.9)	49.2 (46.0–52.5)	44.6 (41.0–48.2)	41.6 (38.3–44.9)	<0.01
DASH	25.3 (23.9–26.6)	22.4 (21.1–23.8)	21.5 (19.6–22.7)	20.0 (18.6–21.5)	<0.01

Least square means and 95% confidence intervals of the HEI-2010, AHEI, and DASH are presented per DII quartile using generalized linear models. DII Quartile Ranges: 1 = −4.93 to −0.90 (n=106); 2 = −0.89 to 1.02 (n=108); 3 = 1.03 to 2.50 (n=107); 4 = 2.51 to 6.23 (n=106). Higher scores on the HEI-2010, AHEI, and DASH are more favorable and indicate a 'healthier' diet. Adjustments: All models adjusted for education, employment, number of children, current dieting status, race, age, social approval, thinness subscale from the Eating Disorder Inventory, cognitive restraint subscale of the Three-Factor Eating Questionnaire, body mass index (kg/m²), percent body fat, and waist-to-hip ratio. Abbreviations: DII = Dietary Inflammatory Index; HEI = Healthy Eating Inventory; AHEI = Alternative Healthy Eating Index; DASH = Dietary Approaches to Stop Hypertension. p: 1 vs. 4 represents the p-value for the difference between DII quartile 4 and 1 determined by generalized linear models. p:cont represents the p-value for the linear relationship between the DII and each index determined by generalized linear models.