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Dietary Adequacy of Children with Autism Compared to Controls and the Impact of Restricted Diet

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Abstract

Objective—Children with autism may consume a restricted diet relative to typical peers, whether due to therapeutic measures or sensory sensitivities. Our objective was to compare children with autism to both typically developing and developmentally delayed children on nutrient and food group intake and overall diet quality and to evaluate the impact of diet restriction.

Methods—Three-day food records and interview information were analyzed from 69 children with autism, 14 children with developmental delay, and 37 typically developing children, drawn from a larger longitudinal study.

Results—Children with autism did not differ significantly from children with other developmental delays on any dietary measures. Although there were differences in average intake of some nutrients between autism and typical controls, only calcium and dairy were also less likely to be consumed in adequate amounts by the autism group. Intentional diet restriction accounted for most of the differences between autism and typical controls. On average, all groups had inadequate fiber, vitamin D, and vegetable intake. Inadequate intake of folate, grains, and dairy was noted for the autism subgroup with intentional diet restrictions. Children in the autism group not following a restricted diet received significantly worse Healthy Eating Index-2005 scores than those following a restricted diet and typical controls. These differences were not nutritionally significant.

Conclusion—When evaluating nutritional adequacy of children with autism, special consideration should be given to calcium, folate, dairy, and grains. Diets of all children with autism should be evaluated for idiosyncratic deficiencies due to unique dietary patterns.

Autism is a neurodevelopmental disorder characterized by impairment in reciprocal social interaction and communication and by the presence of restricted and repetitive behaviors (APA, 1, 2). Interest has surrounded the relationship between the behaviors and symptoms associated with autism spectrum disorder (ASD) and dietary intake. One behavior often associated with ASD that affects dietary intake is selective eating (3). In addition, specific dietary restrictions (e.g., gluten-free (GF) or casein-free (CF) diets) are sometimes used as a therapeutic intervention by parents with the goal of improving behavior and/or

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gastrointestinal symptoms (4). Both selective eating and intentional diet restriction can potentially impact dietary adequacy.

Intake of calories and protein does not appear to be compromised in ASD (5-7). However, evidence suggests that intake of several vitamins and minerals may be lacking in children with ASD when compared to both recommended levels and control samples. These micronutrients include: vitamins A, D, and K, and calcium (5, 8-10). Zimmer and colleagues (11) investigated the nutrient intakes for a group of children with autism who had selective eating and who were not following intentional dietary restrictions. The researchers found an increased risk for inadequate intake of vitamin D, vitamin B12, calcium, and zinc in children with autism who had selective eating compared to typically developing controls, but also found a within-autism difference: an increased risk for inadequate intake of calcium in selective eaters compared to non-selective eaters. Case reports also document vitamin A deficiency in children with ASD with self-limited diets (12, 13).

The effects of intentional diet restriction (e.g., GF, CF diet) on nutrient intake also have been examined. Gluten is a protein found in wheat, rye, and barley and casein is a protein found in milk. Two studies showed that within a sample of children with ASD, no differences were detected in nutrient inadequacies between those following and those not following a restricted diet (6, 14). Failure to detect a difference may have been due to small sample size or failure to confirm adherence to reported diet restrictions. In contrast, Herndon et al. (5) found that intentional diet restriction accounted for the lower intake of calcium in an ASD sample compared to control subjects.

Adequacy of food group intake in ASD has also been explored, with studies revealing consumption of significantly fewer servings of vegetables compared to typically developing controls (10, 15, 16). Shearer et al. (17) reported that intake of dairy by children with autism was significantly lower than in typical controls; and in another sample, dairy intake was significantly lower among children with ASD compared to controls even when subjects following a casein-free diet were excluded from analysis (5).

Several key areas are important to consider when evaluating the nutrient and food group intakes of children with ASD: (a) the methodology used for quantifying nutrient intake, (b) reference values and control groups used, and (c) consideration of the heterogeneity of eating patterns within the ASD population. When determining nutrient intake among subjects with ASD, it is important to note that specialized GF and CF food products are not routinely indexed in nutrient analysis databases, such as the Nutrition Data System for Research software (18). These specialized products are typically not enriched/fortified with key nutrients, such as folate or iron (19). Therefore, substituting a conventional enriched or fortified product in nutrient analysis may lead to overestimation of these enriched or fortified nutrients and thus failure to detect nutrient deficiencies in those consuming GF/CF diets. In the literature, there has been little mention of the methodology used in analyzing nutrient content of specialized GF or CF food products.

Second, comparison both to appropriate reference values and control groups is important. When evaluating nutrient intakes of a group, the Institute of Medicine recommends comparison to the Estimated Average Requirement (EAR; average need of a group) instead of the Recommended Dietary Allowance (RDA; equal to the EAR plus two standard deviations) (20). Comparison to the RDA overestimates the frequency of inadequate nutrient intake. With respect to control groups, studies have used primarily typically developing children and have not included controls with non-ASD developmental delay, failing to establish if the differences from typical controls are specific to ASD or also present in other developmental disabilities.

Third, most studies have combined children with ASD into a homogenous group, failing to examine the isolated effects of selective eating or intentional diet restriction on diet adequacy and quality. When examined, reported intentional diet restrictions have not been verified.

The goal of this study was to address each of these issues in assessing both the quantitative adequacy and the quality of dietary intake among children with autism compared to children with other types of developmental delay and children with typical development. Further, we sought to isolate the impact of restrictive diets. Our main objectives were to assess and compare nutrient intake, food group intake, and diet quality among groups with autism, non-autistic developmental delays, and typical development, and to determine the impact of intentional diet restriction on these constructs.

Methods

Participants

Participants were drawn from a longitudinal study conducted in the Pediatrics and Developmental Neuroscience Branch of the National Institute of Mental Health. Children were recruited from the community to participate if they were between the ages of 1 and 6 years, and were followed annually. The study included comprehensive behavioral and medical evaluations and did not specify examination of dietary intake in recruitment materials. Following diagnostic procedures, children were assigned to one of three groups: autism (AUT), non-ASD developmental delay (DD), and typically developing (TYP). Children were included in the AUT group if they met DSM-IV criteria for autistic disorder based on research-reliable administrations of the Autism Diagnosis Interview-Revised (ADI-R or a Toddler version; 21), the Autism Diagnostic Observation Schedule (ADOS; 22), and clinical judgment. Children were included in the DD group if developmental quotient scores were more than 1.5 standard deviations below the mean on either the Mullen Scales of Early Learning (23) or the Differential Ability Scales, Second Edition (24) and if ASD was ruled out through clinical assessment and administration of the ADI-R and ADOS. Typically developing controls were included if there was no history of delays; there was no ASD in the immediate family; full scale IQ scores were no more than 1.5 standard deviations below the mean; and ADI-R, ADOS, and clinical assessment revealed no concerns about autism. This research was approved by the National Institutes of Health Combined Neurosciences Institutional Review Board (NCT00298246).

Dietary Intake

Prior to one of the study visits, caregivers for all subjects in the longitudinal study were asked to complete a 3-day food record for their child. Written instructions explicitly outlined methods for recording the description of food and portion size consumed, and families were encouraged to provide food labels, brand names, and recipes. They were requested to record all food and non-water beverages their child consumed for a period of three consecutive days, including two weekdays and one weekend day, and to select days expected to reflect typical intake. Caretakers were asked to indicate if the recorded intake was atypical, and to provide an explanation. A registered dietitian reviewed each item on the completed food records with the caregiver in person to obtain additional details of food descriptions and portion sizes using visual cues to maximize accuracy and completeness. Dietary intake data were analyzed using Nutrition Data System for Research (NDS-R) software versions 2008-2011 developed by the Nutrition Coordinating Center (NCC), University of Minnesota, Minneapolis, MN (18). Approximately 60 GF and CF food items not found in the NDS-R database were added by the NCC upon request. The NCC returned food resolutions that were the best match for calories, protein, fat, carbohydrate, sodium and

nutrients of interest that were specified through use of a calculation in which amounts of the major ingredients were adjusted so that the nutrient values of the ingredients best matched the nutrient information of the new food and fell within NCC's nutrient tolerances. Days of food records that had been labeled as "atypical" by the family were removed based on the registered dietitian's determination.

Food records of two or more days were analyzed and an average intake was obtained. The prevalence of nutrient inadequacy was assessed using the EAR cut-point method (20). Comparison to RDA was also assessed; these results are available as a supplemental table. Adequate intake (AI) was used when EAR was not available. Estimated Energy Requirement (EER), the average dietary energy intake predicted to maintain energy balance consistent with good health, was used for the calorie goal (25). A wide range of nutrients was assessed; the full list can be found in Table 2. The average number of servings consumed within each food group (grains, fruits, vegetables, dairy, and protein) was also obtained. The number of recommended servings for each food group was determined according to the child's calorie goal as outlined in the 2010 Dietary Guidelines (26). Legumes were included in the vegetable group, while soy products (e.g., tofu, tempeh, vegetarian burgers) were included in the protein group. Non-dairy milk substitutes (e.g., soy, rice, almond, and hemp milks) were classified as dairy.

Finally, the Healthy Eating Index-2005 (HEI; 27) was calculated to standardize the overall dietary adequacy and quality for each participant. The HEI is based on the 2005 Dietary Guidelines and comprises the following components: total fruit, whole fruit, total vegetables, dark green and orange vegetables and legumes, total grains, whole grains, milk, meat and beans, oils, saturated fat, sodium, and calories from solid fat, alcohol, and added sugar. A score of up to 100 is possible where higher scores reflect higher diet quality. The estimated average score from a 2003-2004 national dataset for children aged 2-11 was approximately 57 (28). The reliability and validity of the HEI were established by the original authors (29). For imputation to the HEI, food group serving totals obtained from NDS-R output reports were converted to Dietary Guideline Servings using methods described elsewhere (30, 31). Dairy substitutes were included in the milk group. For fats and oils, the predominant form (solid fat or oil) was used to determine the assignment. When no predominant fat or oil was identified for a food, monounsaturated and polyunsaturated fatty acids were assigned to oils and the saturated and *trans* fats were assigned to solid fats. The HEI could not be calculated for three children because the Dietary Guidelines apply only to ages two years and older.

Classification of intentionally restricted diets—All collected food records were reviewed to identify level of adherence to a GF and/or CF diet. Gluten-containing and casein-containing foods are common in a typical diet, so the absence of foods that contain these components combined with the presence of GF and/or CF food substitutions was considered evidence of a GF and/or CF diet restriction. As soy is not pervasive in most diets, its absence from a food record was not a sufficient criterion to unequivocally indicate an intentional soy restriction. Therefore, the level of soy restriction was determined only for subjects who reported a soy restriction, or who were following other diet restrictions. Food records were also analyzed for adherence to other reported diet patterns, such as body ecology diet, specific carbohydrate diet, or Feingold diet. Subjects were classified in the "restricted diet" subgroup if sources of gluten and/or casein were completely absent from the food records and if GF and/or CF food substitutions were present. The remaining subjects in the AUT group were assigned to the "not-restricted diet" subgroup. Food records and parent-reported data on intentional diet restriction were typically collected at different study visits. As intentional diet restriction may change over time, the level of adherence to parent-reported diet restrictions could not be determined.

Other measures

Blood samples were obtained within 3 months of the food record; hematocrit levels (% red blood cells), mean corpuscular volume (MCV, fL), and ferritin levels (ng/mL) are reported. Stadiometers (for height) and electronic scales (for weight) were calibrated regularly. Height, weight, and body mass index (BMI) z-scores for each subject were calculated by age and sex using reference data from the National Health and Nutrition Examination Survey (NHANES; 32). BMI was not calculated for three children because their ages were less than 2 years.

The Short Sensory Profile (SSP; 33) was administered to most participants at the baseline visit. The SSP contains a subscale, *Taste/Smell Sensitivity*, which comprises four items relating to eating selectivity due to sensory preferences (taste, smell, texture, temperature). Each item is rated on a 5-point scale from “always” to “never,” resulting in a possible score of 20 (where lower scores indicate greater sensitivity). The SSP is appropriate for children as young as 3 years so only data from children 3 years and above were included for this measure. Due to limited psychometric data on the SSP, the measure was explored only in relation to the standardized measure of dietary quality, the HEI.

Statistical Analysis

Some of the data were not normally distributed and were subsequently $\log_{10}$ transformed (34). This transformation resulted in approximately normal distributions for all variables. With respect to the food group variables (percent of recommended daily servings consumed), the distributions of the data were not affected by transformation. The non-normal distributions were similar in each of the subgroups, so it was determined that outliers were not the cause. Thus, the food group data were transformed into binary variables, with a cut-point that signified adequate intake (at least 100% recommended servings). Food group variables *were not* analyzed as continuous variables.

Two sets of analyses were performed on the dependent variables (including nutrient intakes, food group servings, and HEI score): among diagnostic groups (AUT versus DD versus TYP) and between restricted diet and not-restricted diet within AUT. ANOVA was used for between-group comparisons; $\log_{10}$ transformed variables were used where necessary. In some cases, the assumption of homogenous variances was not met; for these analyses, Welch's robust test is reported. Where needed, post-hoc tests were either Scheffe (robust to unequal sample size) or Games-Howell (robust to non-homogenous variances). To assess the clinical significance of differences in nutrient and food group intake between groups, the frequency of intakes $\geq 100\%$ EAR/AI or recommended servings (i.e., adequate) were assessed with Pearson's chi-squared (or Fisher's Exact Test when at least one cell had an expected frequency of less than five). To partially correct for the large number of tests, alpha was set to 0.01. SPSS version 19.0 was used for all analyses (35).

Results

Participant Characteristics

Participant characteristics (including maternal education as an approximation of socioeconomic status) are shown in Table 1. One hundred thirty-four participants completed food records (AUT, $n = 76$; DD, $n = 16$; TYP, $n = 42$). The food records for 14 participants (AUT, $n = 7$; DD, $n = 2$; TYP, $n = 5$) were unusable due to either atypical intake on the days recorded or insufficient detail recorded. The final sample of 120 comprised $n = 69$ in the AUT group, $n = 14$ in the DD group, and $n = 37$ in the TYP group. The majority of participants ($n = 104$, 87%) had three valid days of records and 16 (13%) participants had two valid days. The sample was predominately male in each of the subgroups and groups

did not differ significantly on age. As expected, the groups differed significantly on nonverbal cognitive ability.

Reported dietary supplements were recorded during the study and grouped into broad categories (Table 1). The mean number of supplements used was significantly higher in the AUT group than in DD and TYP. Aside from multivitamins, the majority of supplements were taken by members of the AUT group. Supplement data are presented qualitatively and were not included in the nutritional analysis because we did not have reliable access to brand names and dosages.

Growth and lab measures were tested as proxies for general health, including height, weight, BMI, hematocrit level, MCV, and ferritin level. Differences among diagnostic groups and between diet groups within the AUT sample were tested with ANOVA. No significant differences on any measure were observed.

Diet restrictions—In total, 23 participants (33%) of the AUT group were classified in the restricted diet subgroup: GF ($n = 3$), CF ($n = 5$), GF+CF ($n = 10$), and GF+CF+Soy-Free (SF) ($n = 5$). Five of these 23 were also partially following GF, CF, and/or SF diets and four of the 23 also partially followed the body ecology or Feingold diet. Five additional participants were only partially following a GF and/or CF diet and were classified as not-restricted. One child in the DD group followed a diet restriction (GF+CF+specific carbohydrate diet). No children in the TYP group followed a restricted diet. The restricted diet subgroup did not differ from the remainder of the AUT group on age, sex, or nonverbal developmental quotient (NVDQ), though they did use significantly more dietary supplements.

Differences between Diagnostic Groups

Nutrient and food group intake and HEI score are presented in Table 2. As the data were not normally distributed in many cases, the median of the values is presented alongside the mean and standard deviation and descriptives for variables that were analyzed as $\log_{10}$ transformed are also presented. ANOVA was used to evaluate between-diagnostic group differences on macronutrient and micronutrient intake (Table 2). The DD group did not differ from the AUT group on consumption of any nutrient, but both were significantly less likely to consume adequate calcium compared to the TYP group. Relative to the TYP group, the AUT group was significantly higher in percent of calories from monounsaturated fats. Children in the AUT group consumed significantly less vitamin A, vitamin D, riboflavin, folate, and calcium than the TYP group. However, only group differences on calcium were associated with inadequate intake (Table 2).

Mean percent recommended servings for each food group (grains, fruits, vegetables, dairy, and protein), were also dichotomized at 100%. There were no differences among diagnostic groups on fruit or vegetable intake (Table 2). The AUT group was significantly less likely to consume at least 100% of recommended dairy servings, and *more* likely to consume at least 100% of recommended protein servings, than the TYP group, while the DD group was less likely than TYP to consume at least 100% of recommended grain servings. Average HEI scores were similar to the value of 57 observed in the 2003-2004 NHANES dataset (28) and did not differ between groups (Table 2). Thus, these data indicate that the autism group had lower calcium intake and a higher prevalence of inadequate calcium intake compared to typical controls, likely related to lower intake of dairy.

Differences Based on Presence of Restricted Diet

Descriptives for macronutrient, micronutrient, and food group intake and HEI score are presented by diet group within the AUT sample in Table 3. Within the AUT group, restricted diet was associated with significantly less intake of several nutrients: Thiamin, riboflavin, niacin, folate, calcium, phosphorus, iron, and selenium (Table 3). Children following a restricted diet consumed significantly more vitamin E and a higher percent of calories from polyunsaturated and monounsaturated fat. However, when these variables were dichotomized to reflect inadequate intake (100%), only the differences in vitamin E and folate remained statistically significant. Within AUT, children following a restricted diet were significantly less likely to consume at least 100% of daily recommended servings of grains and dairy. In summary, children with autism on a restricted diet had significantly lower folate intake and a higher prevalence of inadequate folate intake than those not on a restricted diet, consistent with less intake of grains.

Due to significant differences within the AUT group, it was suspected that the children on restricted diets were driving the observed differences between AUT and TYP. Thus, the restricted diet subgroup was excluded and the data were re-analyzed (data not shown). For most variables, differences between AUT and TYP were no longer significant when the restricted diet group was excluded. However, after subjects with restricted diets were excluded, the AUT group still consumed significantly less calcium [$F(1,81) = 12.32, p = 0.001$], and vitamin D [Welch's $F(1,81) = 11.14, p = 0.001$] than the TYP group. As with the analyses in the full sample, only the calcium was of clinical significance (48% of AUT not-restricted versus 86% of TYP consumed 100% calcium EAR; $\chi^2 = 13.48, p < 0.001$) as a high percentage of subjects in all groups consumed inadequate vitamin D. Excluding the restricted diet subgroup, children in the AUT group were still more likely than TYP to consume at least 100% of the recommended servings of protein (41% versus 14%, $\chi^2 = 7.71, p = 0.006$). In summary, even children with autism who were not on a restricted diet had calcium intake that was both lower than typical controls and more often inadequate.

Although HEI score did not differ between the full AUT and TYP groups, when restricted diet subjects were excluded, AUT scored significantly lower on HEI than TYP [61.91 ± 11.01 versus 68.06 ± 8.50 , respectively; $F(1,78) = 7.46, p = 0.008$]. This was due to a higher HEI score in the restricted diet subgroup than the not-restricted diet subgroup [69.36 ± 10.32 versus 61.91 ± 11.02 , respectively; $F(1,66) = 7.26, p = 0.00$].

Relationship of Short Sensory Profile to HEI

SSP *Taste/Smell Sensitivity* scores were available for 78% of participants ($n=53$ AUT, $n=13$ DD, $n=27$ TYP). Mean scores for both AUT (12.62 ± 5.10) and DD (14.23 ± 5.72) were rated lower (more sensitive) than TYP (18.19 ± 2.60), but post-hoc tests showed statistical significance only between AUT and TYP [$F(2,90) = 13.01, p < 0.001$]. Within the AUT group, children on a restricted diet did not differ from others (12.58 ± 4.8 versus 12.65 ± 5.30 , respectively). Scores on the *Taste/Smell Sensitivity* subscale accounted for very little of the variance in HEI score and the correlation failed to reach statistical significance in the full sample [$F(1, 91) = 5.18, p = 0.03; R^2 = 0.05$] and within the AUT group [$F(1, 51) = 3.56, p = 0.07; R^2 = 0.07$]. Thus, sensory sensitivities, as measured by the SSP, did not meaningfully impact overall healthy eating.

Discussion

In this study, the analysis of dietary intake (not including dietary supplements) of children with autism revealed few clinically meaningful deficiencies in nutrient and food group intake and dietary quality in the autism group as a whole or in the restricted diet subgroup. A

significant strength of this study was the relatively large sample of children with confirmed GF and/or CF diets, which allowed for assessment of the diets' effects on nutrient intake. One-third of AUT subjects were completely following a GF, CF, and/or SF diet. This proportion is higher than reported elsewhere (5, 6, 36, 37).

Overall, significantly lower mean percent intake for several nutrients and a higher risk for inadequate intake of the dairy food group were observed in AUT versus TYP. However, further analyses revealed that the children on restricted diet were primarily responsible for the differences between AUT and TYP; when they were removed from analysis, significant differences remained for only calcium, and vitamin D. Thus, the differences between AUT vs. TYP can be mostly explained by the large proportion of subjects in the AUT group who were following a GF and/or CF diet and not adequately substituting other dietary sources of these nutrients. Without dietary compensation, a GF and/or CF diet can impact nutrient intake in predictable ways. Cow's milk is a good source of vitamin A, vitamin D, riboflavin, calcium, and phosphorus, and refined gluten-containing grains are typically enriched or fortified with iron, thiamin, riboflavin, niacin, and folic acid; whereas, most GF grain products are not enriched or fortified with these respective nutrients (19).

That intentional diet restriction accounted for most of the differences between AUT and TYP is not surprising. However, the finding that differences in calcium and vitamin D intake between AUT and TYP were independent of diet restriction was unexpected and potentially due to partial intentional restriction of casein in the not-restricted diet group. Alternatively, as both AUT and DD had a higher risk of inadequate intake of calcium relative to TYP, calcium deficiency may be an issue for the broader population of children with developmental delay. Of note, an association between selective eating and decreased intake of calcium has been reported (11). Regardless, clinical relevance of these findings was illustrated in a study of autism which found significantly lower bone cortical thickness compared to reference data, even after adjustment for height, bone age, CF diet restriction, and anti-epileptic medication use (38). Thus, ensuring adequate intake of calcium and vitamin D in subjects with autism through diet or supplementation may be important for optimal bone health.

If intake of a nutrient is adequate across groups, then mean differences in intake are less meaningful. Few studies have adequately characterized this important aspect of differences in nutrient intake. In the current study, meaningful differences were those in which both lower mean intake and a lower proportion of adequate intake were observed. Although AUT and TYP differed in mean intake of several nutrients, only calcium was adequately consumed less often in the AUT group. This was observed for those with and without the restricted diets. A nutritionally meaningful difference in folate was observed within the AUT group between restricted and not-restricted diet groups, most likely due to consumption of unfortified GF grains and inadequate intake of grains overall. The frequency of adequate vitamin D, fiber, and vegetable intake was low in all groups; therefore, these nutrients and food group were of concern regardless of the diagnostic group.

The main intention of this study was to assess the adequacy of diets of children with autism. Although an interesting adjunct to this study would have been quantification of the nutrient contribution from dietary supplements, we were unable to include dietary supplements in the analysis because we did not have access to name brands and dosages. As many participants in the autism group were reported to take multivitamins and mineral supplements (e.g., calcium, magnesium, and zinc), the dietary deficiencies we identified may have been compensated for by use of dietary supplements. However, it is still important for clinicians to be aware that calcium and folate are nutrients likely to be deficient in the diets of children with autism so that compensatory measures can be taken when needed.

Only one other study analyzed 3-day food records using a nutrient analysis database that included GF and CF foods and compared nutrient intakes to the EAR (6). They reported that, compared to NHANES controls, the ASD group had a higher prevalence of inadequate intake of vitamin A, vitamin C, phosphorus and zinc in specific age groups. These results were not replicated in our study, perhaps due to smaller sample size or differences in comparison groups. However, they did find a high frequency of inadequate intake of calcium and vitamin D in their sample, consistent with our results. In that study, no difference in the number of nutrient inadequacies was observed between subjects with reported restricted and not-restricted diets, though the researchers did not verify the degree of actual diet restriction in these subjects.

The present study is the first known report to use HEI as a measure of diet adequacy and quality in an autism sample. Total HEI scores across all diagnostic groups were slightly higher than, but comparable to, those reported in a large sample of healthy children in a similar age range from NHANES (28). Regardless of differences observed within the AUT group and between the AUT not-restricted and TYP groups, it is important to note that the average values were in a range consistent with the broader population. The difference in HEI between AUT not-restricted and TYP is likely explained by dairy intake; however, the higher HEI score in AUT restricted versus AUT not-restricted was surprising. This difference did not suggest *poor* HEI in the not-restricted subgroup, as both groups scored above the available national average, and should be interpreted cautiously given the dietary deficiency of folate for the AUT restricted group noted in other analyses.

Nadon et al. (39) reported that sensory sensitivities (measured by total SSP score and some individual components that included *Taste/Smell Sensitivity*) were associated with a variety of eating problems (including limited food preferences), though the mean differences were small and not directly indicative of a relationship to eating selectivity. In the current study, we did not observe a strong link between the SSP *Taste/Smell Sensitivity* subscale and the HEI. However, these data are not conclusive, owing to the potential weakness of the SSP as a proxy for selectivity. Furthermore, selective eating is likely to manifest in ways that are unique to each child, so the absence of group effects does not negate the need for diet assessment for individual children with food selectivity. Future research on the link between autism, eating selectivity, and nutrient intake may help to interpret these findings.

Several potential limitations of this study are worthy of discussion. Although the use of caregiver-reported 3-day food records is standard practice in the field, there are inherent problems. Quantities of consumed food are often estimated by caregivers rather than accurately measured and there may be biased reporting by caregivers toward a healthier diet. Furthermore, some authors suggest that 3 consecutive days is inadequate to estimate the average true intake of a group for all nutrients in children (40, 41). The use of food databases affords systematic calculation of nutrient content, but also requires approximation for foods that do not have exact matches, though we attempted to improve accuracy by adding the specialized GF and CF foods into the database. Finally, HEI may not have best captured the dietary implications of selective eating through inability to detect low food variety within each food group, which has been reported in autism (42, 43).

In conclusion, the results of this study suggest that overall dietary adequacy of children with autism is comparable to those with other non-spectrum delays and typically developing peers. However special consideration should be given to intake of calcium and dairy by children with autism. For those following an intentional diet restriction, folate and grain intake also may be compromised. However, given the selective eating patterns common to children with ASD, on an individual level, children may present with other dietary deficiencies specific to their diet patterns. Our study illustrates the importance of accounting

for the effects of intentional diet restriction, such as the GF/CF diet, when assessing diet adequacy in autism. Future studies should focus on evaluating the effects on diet of selective eating, using more direct measures of food selectivity. In summary, while every patient is unique, clinicians treating children with autism should pay particular attention to ensuring adequate intake of calcium through diet or supplementation. If the child is also on an intentional diet restriction, supplementation with folate may be warranted.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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References

1. American Psychiatric Association. Diagnostic and statistical manual of mental disorders: DSM-IV-TR. 4th. Washington, DC: American Psychiatric Association; 2000. Task Force on DSM-IV.
2. Levy SE, Mandell DS, Schultz RT. Autism. *Lancet*. Nov 7; 2009 374(9701):1627–38. [PubMed: 19819542]
3. Cermak SA, Curtin C, Bandini LG. Food selectivity and sensory sensitivity in children with autism spectrum disorders. *J Am Diet Assoc*. 2010; 110(2):238–46. [PubMed: 20102851]
4. Srinivasan P. A review of dietary interventions in autism. *Ann Clin Psychiatry*. 2009; 21(4):237–47. [PubMed: 19917213]
5. Herndon AC, DiGiuseppi C, Johnson SL, et al. Does nutritional intake differ between children with autism spectrum disorders and children with typical development? *J Autism Dev Disord*. 2009; 39(2):212–22. [PubMed: 18600441]
6. Hyman SL, Stewart PA, Schmidt B, et al. Nutrient intake from food in children with autism. *Pediatrics*. 2012; 130(2):S145–53. [PubMed: 23118245]
7. Schmitt L, Heiss CJ, Campbell EE. A comparison of nutrient intake and eating behaviors of boys with and without autism. *Top Clin Nutr*. 2008; 23(1):23–31.
8. Bandini LG, Anderson SE, Curtin C, et al. Food selectivity in children with autism spectrum disorders and typically developing children. *J Pediatr*. 2010; 157(2):259–64. [PubMed: 20362301]
9. Lockner DW, Crowe TK, Skipper BJ. Dietary intake and parents' perception of mealtime behaviors in preschool-age children with autism spectrum disorder and in typically developing children. *J Am Diet Assoc*. Aug; 2008 108(8):1360–3. [PubMed: 18656577]
10. Johnson CR, Handen BL, Mayer-Costa M, et al. Eating habits and dietary status in young children with autism. *J Dev Phys Disabil*. 2008; 20(5):437–48.
11. Zimmer MH, Hart LC, Manning-Courtney P, et al. Food variety as a predictor of nutritional status among children with autism. *J Autism Dev Disord*. Apr; 2012 42(4):549–56. [PubMed: 21556968]
12. Tanoue K, Matsui K, Takamasu T. Fried-potato diet causes vitamin A deficiency in an autistic child. *JPN J Parenter Enteral Nutr*. Nov; 2012 36(6):753–5. [PubMed: 22318966]
13. McAbee GN, Prieto DM, Kirby J, et al. Permanent visual loss due to dietary vitamin A deficiency in an autistic adolescent. *J Child Neurol*. Oct; 2009 24(10):1288–9. [PubMed: 19638639]
14. Cornish E. Gluten and casein free diets in autism: a study of the effects on food choice and nutrition. *J Hum Nutr Dietet*. 2002; 15:261–9.
15. Evans EW, Must A, Anderson SE, et al. Dietary patterns and body mass index in children with autism and typically developing children. *Res Autism Spectr Disord*. 2012; 6(1):399–405. [PubMed: 22936951]

16. Emond A, Emmett P, Steer C, et al. Feeding symptoms, dietary patterns, and growth in young children with autism spectrum disorders. *Pediatrics*. 2010; 126(2):e337–e42. [PubMed: 20643716]
17. Shearer TR, Larson K, Neuschwander J, et al. Minerals in the hair and nutrient intake of autistic children. *J Autism Dev Disord*. 1982; 12(1):25–34. [PubMed: 6896512]
18. Schakel SF. Maintaining a nutrient database in a changing marketplace: Keeping pace with changing food products- a research perspective. *J Food Compos Anal*. 2001; 14:315–22.
19. Thompson T. Folate, iron, and dietary fiber contents of the gluten-free diet. *J Am Diet Assoc*. 2000; 100(11):1389–1396. [PubMed: 11103663]
20. Otten, JJ.; Hellwig, JP.; Meyers, LD. DRI, Dietary Reference Intakes: The Essential Guide to Nutrient Requirements. National Academies Press; 2006.
21. Lord C, Rutter M, Le Couteur A. Autism Diagnostic Interview-Revised: A revised version of a diagnostic interview for caregivers of individuals with possible pervasive developmental disorders. *J Autism Dev Disord*. 1994; 24(5):659–85. [PubMed: 7814313]
22. Lord C, Risi S, Lambrecht L, et al. The Autism Diagnostic Observation Schedule-Generic: A standard measure of social and communication deficits associated with the spectrum of autism. *J Autism Dev Disord*. Jun; 2000 30(3):205–23. [PubMed: 11055457]
23. Mullen, EM., editor. Mullen Scales of Early Learning. Circle Pines, MN: American Guidance Service; 1995.
24. Elliott, CD., editor. Manual for the Differential Ability Scales. Second. San Antonio, TX: Harcourt Assessment; 2007.
25. Food and Nutrition Board Institute of Medicine. Dietary Reference Intakes for Energy, Carbohydrate, Fiber, Fat, Fatty Acids, Cholesterol, Protein, and Amino Acids (Macronutrients). Washington, DC: National Academies Press; 2005.
26. U.S Department of Agriculture and U.S. Department of Health and Human Services. Dietary Guidelines for Americans, 2010. 7th. Washington, DC: U.S. Government Printing Office; 2010.
27. Guenther, PM.; Reedy, J.; Krebs-Smith, SM., et al. Development and Evaluation of the Healthy Eating Index-2005: Technical Report. Center for Nutrition Policy and Promotion, U.S. Department of Agriculture; 2007. Available at: <http://www.cnpp.usda.gov/HealthyEatingIndex.htm>
28. Fungwe, T.; Guenther, PM.; Juan, W., et al. The quality of children's diets in 2003-04 as measured by the Healthy Eating Index-2005. *Nutrition Insight* 43. 2009. Available at: <http://www.cnpp.usda.gov>
29. Guenther PM, Reedy J, Krebs-Smith SM, et al. Evaluation of the Healthy Eating Index-2005. *J Am Diet Assoc*. 2008; 108(11):1854–64. [PubMed: 18954575]
30. Bowman, SA.; Friday, JE.; Moshfegh, A. Food Surveys Research Group. MyPyramid Equivalents Database, 2.0 for USDA Survey Foods, 2003-2004. Beltsville Human Nutrition Research Center, Agricultural Research Service, U.S. Department of Agriculture; Beltsville, MD: 2008. Online Available at: <http://www.ars.usda.gov/ba/bhnrc/fsrg>
31. Miller PE, Mitchell DC, Harala PL, et al. Development and evaluation of a method for calculating the Healthy Eating Index-2005 using the Nutrition Data System for Research. *Public Health Nutr*. 2011; 14(2):306–13. [PubMed: 20576195]
32. McDowell, MA.; Fryar, CD.; Hirsch, R., et al. Anthropometric reference data for children and adults: US population, 1999-2002. *Advance Data From Vital and Health Statistics*. Jul 7. 2005 Available at: <http://www.cdc.gov/nchs/data/ad/ad361.pdf>
33. Dunn, W. Short Sensory Profile. The Psychological Corporation; 1999.
34. Wickens, TD.; Keppel, G. Design and analysis: A researcher's handbook. Englewood Cliffs, NJ: Prentice-Hall; 2004.
35. SPSS Statistics for Windows Version 19.0. Armonk, NY: IBM Corp; 2010.
36. Goin-Kochel RP, Myers BJ, Mackintosh VH. Parental reports on the use of treatments and therapies for children with autism spectrum disorders. *Res Autism Spectr Disord*. 2007; 1(3):195–209.
37. Adams JB, Audhya T, McDonough-Means S, et al. Nutritional and metabolic status of children with autism vs. neurotypical children, and the association with autism severity. *Nutr Metab (Lond)*. 2011; 8(1):34. [PubMed: 21651783]

38. Hediger ML, England LJ, Molloy CA, et al. Reduced bone cortical thickness in boys with autism or autism spectrum disorder. *J Autism Dev Disord.* 2008; 38(5):848–56. [PubMed: 17879151]
39. Nadon G, Feldman DE, Dunn W, et al. Association of sensory processing and eating problems in children with autism spectrum disorders. *Autism Res Treat.* 2011; 2011:541926. Epub 2011 Sep 22. [PubMed: 22937249]
40. Huybrechts I, De Bacquer D, Cox B, et al. Variation in energy and nutrient intakes among pre-school children: implications for study design. *Eur J Public Health.* 2008; 18(5):509–16. [PubMed: 18524803]
41. Erkkola M, Kytälä P, Takkinen HM, et al. Nutrient intake variability and number of days needed to assess intake in preschool children. *Br J Nutr.* 2011; 106(1):130–40. [PubMed: 21679478]
42. Schreck KA, Williams K. Food preferences and factors influencing food selectivity for children with autism spectrum disorders. *Res Dev Disabil.* 2006; 27(4):353–63. [PubMed: 16043324]
43. Schreck KA, Williams K, Smith AF. A comparison of eating behaviors between children with and without autism. *J Autism Dev Disord.* 2004; 34(4):433–8. [PubMed: 15449518]