

Feeding Problems and Nutrient Intake in Children with Autism Spectrum Disorders: A Meta-analysis and Comprehensive Review of the Literature

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Abstract We conducted a comprehensive review and meta-analysis of research regarding feeding problems and nutrient status among children with autism spectrum disorders (ASD). The systematic search yielded 17 prospective studies involving a comparison group. Using rigorous meta-analysis techniques, we calculated the standardized mean difference (SMD) with standard error and corresponding odds ratio (OR) with 95 % confidence intervals (CI). Results indicated children with ASD experienced significantly more feeding problems versus peers, with an overall SMD of 0.89 (0.08) and a corresponding OR of 5.11, 95 % CI 3.74–6.97. Nutrient analyses indicated significantly lower intake of calcium (SMD: -0.65 [0.29]; OR: 0.31, 95 % CI 0.11–0.85) and protein (SMD: -0.58 [0.25]; OR: 0.35, 95 % CI: 0.14–0.56) in ASD. Future research must address critical questions regarding the cause, long-term impact, and remediation of atypical feeding in this population.

Keywords Diet · Food selectivity · Mealtime problems · Nutrition · Picky eating · Pediatric feeding disorders

Introduction

Autism spectrum disorders (ASD) represent a range of complex developmental disabilities involving severe impairments in social interaction and communication accompanied by behavioral inflexibility, repetitive behaviors, and/or restricted interests (APA 2000). In addition to the core diagnostic features, children with ASD often present with comorbid ear infections (Konstantareas and Homatidis 1987), increased use of antibiotics (Niehus and Lord 2006), constipation (Ibrahim et al. 2009), possible gastroenterological disturbances (Horvath et al. 1999), and an array of challenging behaviors, including self-injury, severe tantrums, feeding problems, aggression, toileting, and sleep disturbances (Whiteley 2004; Herzinger and Campbell 2007; Seiverling et al. 2010). Of these concerns, feeding arguably involves the most essential of human activities, necessary to assure appropriate development and sustain life. Chronic feeding problems place children at risk for a number of detrimental medical and developmental outcomes, including malnutrition, growth retardation, invasive medical procedures (e.g., placement of a feeding tube), developmental delays, psychological and social deficits, and poor academic achievement (Kerwin 1999; Sharp et al. 2010). Researchers, however, have only recently begun to systematically investigate eating and nutrient intake patterns associated with ASD, and many questions remain regarding prevalence, consequences, and remediation of feeding problems in this population.

Lack of research on this topic is remarkable given the historical link between feeding and ASD. Leo Kanner's initial description of the condition cited atypical eating patterns as prominent in his sample and past diagnostic systems included feeding difficulties as a defining characteristic (Kanner 1943; Ritvo and Freeman 1978). Further,

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the social and behavioral demands of feeding situations tap into all three areas of difficulty displayed by children with ASD. Communication, behavioral flexibility, and social engagement each play important roles in promoting intake, increasing dietary diversity, and assuring the saliency of social reinforcement during meals. Related theories reflect this connection, with different authors positing different etiologies, including idiosyncratic focus on detail, behavioral rigidity, sensory impairments, social skills deficits, and/or communication deficits (Cumine et al. 2000; Ahearn et al. 2001). Finally, research regarding feeding problems in ASD and related dietary vulnerabilities has important implications for a growing interest regarding the use of dietary manipulation (e.g., gluten and/or casein free, GFCF diet) in this population, as well as the possible role of dietary insufficiencies in the pathology of the condition, such as vitamin D (Cannell 2008).

Much of what is known regarding feeding patterns in ASD is based on anecdotal and case reports describing children with ASD as presenting with unusual eating patterns, rituals regarding food preparation/presentation, food refusal and/or displaying strong emotional responses to new foods (Cornish 1998; Ahearn et al. 2001). Food selectivity (by type, texture, and/or presentation) is the feeding problem most often associated with ASD, typically involving strong preferences for carbohydrates, snacks, and/or processed foods while rejecting fruits and vegetables (Ahearn et al. 2001; Schreck et al. 2004; Williams et al. 2005). Many past reports, however, documenting this trend involved children seeking intervention for severe food selectivity, often in the form of behavioral intervention aimed at expanding dietary variety (e.g., Sharp et al. 2010), and a more general picture regarding the eating patterns and nutritional status of all children with ASD has yet to emerge.

Ledford and Gast (2006) conducted the first literature review of feeding problems in ASD, identifying seven studies (381 total children) published between 1994 and 2004. All studies reported significant feeding difficulties, primarily in the form of food selectivity by type and/or texture, with estimates ranging from 46 to 89 % of children with ASD with atypical feeding habits. While providing evidence of widespread feeding problems, large variability in prevalence estimates reflected wide methodological variability among the studies. Less than half of the studies included a comparison group, and the primary method of data collection involved chart audits or study specific questionnaires. In addition, few studies presented information regarding participants' definitive diagnostic status (i.e., autistic disorder, PDD-NOS, Asperger syndrome), with 85 % having no specific ASD diagnosis and no standardized assessment of disability which limits generalizability of the findings.

In a more recent review, Cermak et al. (2010) identified studies investigating food selectivity and nutrient adequacy in ASD. The authors identified 817 participants in 16 studies with two foci: food selectivity (nine studies) or nutritional status related to dietary intake (four studies); three studies spanned both areas of inquiry. Findings suggested food selectivity was a significant problem in ASD; however, Cermak et al. cited the lack of a comparison group, present in only 6 of the 12 studies, as a key limitation to drawing definitive conclusions. Findings regarding the nutritional status of children with ASD were equivocal. Four studies involving comparison groups reported conflicting results, with the nutrient intake of children with ASD described as below, above, or at the same level as typically developing peers. Three remaining studies comparing the nutrient intake of children with ASD to recommended dietary standards also reported both nutrient deficits (e.g., vitamin D) and excesses (e.g., protein); however, no consistent pattern emerged, and lack of comparison groups precluded conclusions as to whether a deviation from recommended levels was unique to ASD.

The works of Ledford and Gast (2006) and Cermak et al. (2010) provide an important foundation for understanding feeding concerns and nutritional status of children with ASD, offering provisional evidence that feeding problems may be endemic in the ASD population. Recent growth in research into feeding in ASD, combined with the availability of quantitative procedures for synthesizing outcome data, present the opportunity for a more detailed analysis of the extant literature. The current review sought to (a) survey the medical, habilitative, and psychological literature in order to identify studies using empirical methods to investigate the feeding behaviors and/or nutritional status of children with ASD and (b) summarize the evidence on the basis of both descriptive and meta-analytic procedures. To address limitations noted in previous reviews, we focused exclusively on prospective research involving a comparison group to quantify the magnitude of feeding problems and/or nutrient deficiencies associated with ASD and used this information to develop ASD-specific recommendations to guide future clinical and research activities in this area.

Method

Study Identification and Eligibility Criteria

Following the guidelines outlined by the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) statement, we searched MedLine, PsychINFO, and PubMed databases (January 1980 and August 2011), reviewed reference lists, and conducted ancestral

and online searches in English language journals for eligible studies. The search parameters included combinations of key words regarding the target population (autism, autistic, autism spectrum disorders, pervasive developmental disorder, PDD-NOS, Asperger syndrome), mealtime-related variables (diet, dietary intake, eating, feeding, food selectivity, nutrition, mealtime behaviors, pediatric feeding disorder), and evaluation methodology (assessment, mealtime observation, food frequency).

We focused on prospective studies utilizing a comparison group to present quantitative information about feeding behaviors and/or nutrient intake in a pediatric population (birth to 18 years of age) with ASD and sought to capture a wide range of children regardless of the presence of feeding related difficulties. As a result, we excluded recent program evaluations (Laud et al. 2009; Sharp et al. 2011) single-subject designed studies (see Sharp et al. 2010 for a summary), and chart reviews of children with ASD evaluated due to atypical feeding patterns (Williams et al. 2005) in order to avoid a known sampling bias. This procedure also excluded studies focusing on the impact of dietary manipulation (e.g., GFCF diet) on nutrition or behavioral functioning (e.g., Elder et al. 2006). To be included in the review, studies also needed to meet the following criteria:

1. Evaluated feeding through a standardized, replicable manner, such as dietary intake (e.g., 3-day food diary), feeding questionnaires [e.g., Children's Eating Behavior Inventory-Revised (CEBI-R); Archer et al. 1991], Brief Autism Mealtime Behavior Inventory (BAMBI; Lukens and Linscheid 2008), study specific questionnaires involving set questions, and/or mealtime observation with a detailed protocol.
2. Included a dependent variable(s) focused on feeding behavior (i.e., chronic food selectivity, food refusal/poor oral intake, and/or behavioral rigidity during meals), nutritional status, or dietary variety. Data obtained through these measures was presented in the study, either descriptively (e.g., frequencies, percentages, means) or statistically (e.g., *p* values, *t* scores).
3. Focused on active chronic feeding concerns (i.e., not studies or items pertaining to historical concerns alone such as feeding during infancy, difficulty transitioning to solids).

Variables Coded, Data Extraction, and Reliability

Data were extracted from articles using a three-phase system. First, all articles identified through the literature were screened for eligibility criteria. We then extracted descriptive information, collecting information regarding study descriptors, participant demographic variables, composition of the comparison group(s), diagnostic

procedures, feeding/nutrient assessment measures, and summary of findings. Characteristics in each of these categories were coded using a standardized checklist system. For feeding behaviors, we categorized item(s) and/or assessment measure(s) and their content based in three categories: food selectivity (e.g., by type, texture, or presentation), food refusal (e.g., refusing food by crying, pushing away food, leaving the table)/poor oral intake (concerns regarding total calories or nutrients consumed), and/or behavioral rigidity during meals (e.g., difficulty eating across environments, insists on rituals at table). If food selectivity was reported, we documented whether the pattern of food intake was analyzed (e.g., preference or rejection of certain types). For dietary information, data collection focused on the following key dietary indicators: vitamin A, C, D, & E, zinc, calcium, iron, fiber, fat, protein, carbohydrates, and total energy (kcal). When available, we also recorded nutritional risk based on the cut point method (Barr et al. 2002), a different approach to assessing dietary status that involves calculating an individual's typical intake of each nutrient, identifying the total number of nutrients falling within established standards (e.g., estimated average requirement), and determining the proportion of children in each group meeting or not meeting recommended levels. The research team involved a registered dietician, who was responsible for calculating nutritional risk, as well as selecting and interpreting specific dietary indicators. To determine growth status, we also recorded anthropometric data (i.e., height, weight, body-mass index) when presented.

Multiple researchers independently coded all studies. The mean inter-rater agreement for categorical data was 97 % (range 87–100 %) with a corresponding Kappa of 0.94 (range 0.79–1). The overall intra-class correlation for interval and continuous data was 0.93 (range 0.54–1). Coder agreement exceeded the 80 % standard widely adopted and recommended during quantitative synthesis of research (Campbell 2003). Due to the wide range of assessment methods and item content related to feeding behaviors in ASD, two members of the research team with expertise in autism and pediatric feeding disorders conducted a third level review of all extracted data to determine inclusion status and classify item/scale content based on the criteria outlined above. The mean inter-rater agreement for items to analyze was 91 % (range 66–100 % across studies) with a corresponding Kappa of 0.80 (range 0.33–1).

Statistical Analysis

To calculate the effect size (ES), we used means (standard deviations) or frequencies (percentages) and, if necessary, we estimated the ES from test statistics (e.g., *Chi Square*, *t* tests). When summary statistics were not presented, we attempted to contact the primary author via email before

using alternative methods and, if unsuccessful, we used exact p values to calculate the ES. If an exact p value was not provided, we adopted a conservative approach to estimating a p value closest to the level provided (Lipsey and Wilson 2001).

The primary goal of the meta-analysis was to determine the overall difference in feeding behavior and/or nutritional status between children with and without ASD. We, therefore, calculated an overall mean study ES when multiple comparisons had been made (Rosenthal and Rubin 1986). In line with these criteria, we combined outcome variables (e.g., food selectivity, food refusal), resulting in a single ES. Likewise, when studies separately presented individual items, or individual subscales, along with total scale scores, only items or scales pertaining to these criteria were used in the present analysis. For nutrient data, we calculated a separate ES estimates for each nutrient across studies. For studies involving multiple comparison groups, we pooled the comparison groups, producing an overall ES. Separate ES estimates for each comparison group [i.e., ASD vs. typically developing peers (TD); ASD vs. siblings (SIB); ASD vs. children with other developmental disabilities (DD)] were also calculated to identify possible moderator variables using the between groups Q test, with a significance level of $p < 0.05$. We did not conduct additional analysis of potential moderators (e.g., age, sex, diagnostic status) given the lack of descriptive data presented in the articles (described below).

Data were entered and analyzed using Comprehensive Meta-Analysis 2 (Borenstein et al. 2005). We converted all ES estimates to standardized mean difference (SMD). For feeding behaviors, a positive SMD ($SMD > 0$) indicated more feeding-related concerns in children with ASD compared with the comparison group. We coded nutritional data so that a negative SMD ($SMD < 0$) indicated more nutritional deficits in children with ASD. The point estimates and standard error were calculated using a random-effects model of meta-analysis (Hunter and Schmidt 2004). We evaluated SMD magnitude using conventional standards (0.2 = small; 0.5 = medium; 0.9 = large; Cohen 1988). To aid in clinical interpretation of outcomes, we also calculated the corresponding odds ratio (OR) with 95 % CIs, with values reflecting the odds of a child with ASD having a feeding difficulty compared to child without ASD.

To assess heterogeneity within subgroups and between studies, effect sizes and associated 95 % CIs were calculated for each subgroup. We also used the Q test to formally determine if heterogeneity was present. To assess the robustness of our results, we conducted a sensitivity analysis, which involved repeatedly calculating the effect size with one study omitted per iteration and comparing the results with the overall study effect. We analyzed the threat of possible publication bias to the validity of the obtained

outcomes using the funnel plot (Egger et al. 1997), failsafe N (Becker 2005), and the trim and fill method (Duval and Tweedie 2000).

Results

Characteristic of Studies and Participants

The search yields 17 articles meeting inclusion criteria out of a pool of 678 possible studies (see Fig. 1). Sixty-five percent of the articles were published in journals specializing in ASD or related DD, with the *Journal of Autism and Developmental Disorders* contributing nearly half of the studies in this area (see Table 1). Ten articles (88 %) were published since 2000; five since 2010. Compared with previous reviews, 2 of the 7 studies (29 %) identified by Ledford and Gast (2006) and 6 of the 16 studies (36 %) summarized by Cermak et al. (2010) met inclusion criteria. Ten articles were unique to this review.

Feeding assessment methods primarily involved estimates of nutrient intake (e.g., 3-day food diary) and questionnaires specific to the study involving single item analysis (Table 2). Standardized questionnaires were utilized in only three studies (18 %). While most studies broadly assessed feeding behaviors using single items or scales (e.g., eats a narrow range of foods, doesn't try new foods), three studies (Bandini et al. 2010; Emond et al.

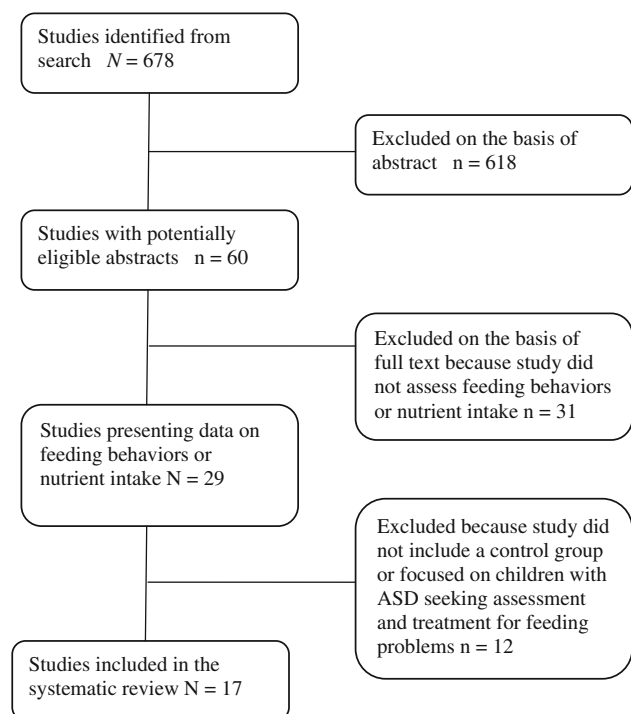


Fig. 1 Flow diagram of included and excluded studies

Table 1 Summary of articles by journal and year of publication

Journal title	n	%
Journal of Autism and Developmental Disorders	7	41
Autism	1	5.9
Journal of the American Dietetic Association	1	5.9
Journal of Developmental and Physical Disabilities	1	5.9
Journal of Learning Disabilities	1	5.9
The Journal of Pediatrics	1	5.9
Pediatrics	1	5.9
Physical & Occupational Therapy in Pediatrics	1	5.9
Research in Autism Spectrum Disorders	1	5.9
Research in Developmental Disabilities	1	5.9
Topics in Clinical Nutrition	1	5.9
Total	17	100
Year published		
2010–present	5	29
2000–2009	10	59
1980–1989	2	12

2010; Zimmer et al. 2012) calculated a dietary variety score based on responses to a food frequency questionnaire, focusing on the number of foods identified as never consumed. Food selectivity represented the primary type of feeding problem assessed among studies, representing 54 % of the items or scales (e.g., eats a narrow variety of foods, obsessive eating habits), 21 % of the items or scales focused on food refusal or poor oral intake (e.g., disruptions/tantrums during meals, throw or spits food), 17 % assessed behavioral rigidity during meals (e.g., eats only in specific places, requires specific utensils), and 7 % involved overlapping content.

The pool of studies involved a total sample of 881 children with ASD. Data regarding feeding behaviors were gathered from 832 (94 %) participants, while 263 children (30 %) from eight studies provided data on micronutrient intake. Only 29 % of studies presented data regarding diagnostic status, resulting in 669 participants (76 %) with a nonspecific ASD diagnosis. In terms of comparison groups, most studies (82 %) involved typically developing peers or children drawn from the general population, followed by studies involving children with developmental or learning disabilities (18 %) or siblings (18 %). Most studies (82 %) reported equivalence between ASD and comparison groups in terms of age. Two studies (12 %) did not statistically analyze possible age difference across groups, while one study reported that the ASD group was significantly older. In terms of gender, the ASD groups tended to involve a higher ratio of males to females compared to the comparison groups; four studies (24 %) statistically analyzed this variable, all reporting higher numbers of males to females in the ASD groups (Table 3).

Growth Status

Seven studies (41 %) involving 426 children presented information regarding anthropometric parameters [e.g., height, weight, or body mass index (BMI)] compared with typically developing peers. Six studies compared mean values between groups, finding no statistically significant differences in anthropometric parameters. One study analyzed the percentage of children in each group identified as overweight (BMI \geq 85th %) or underweight (BMI $<$ 5th %) and reported no difference in the number of children falling into these classifications (Bandini et al. 2010).

Dietary Variety

Ten studies presented detailed food group preferences, six of which supported past reports indicating children with ASD consumed fewer vegetables (Lukens and Linscheid 2008; Johnson et al. 2008; Martins et al. 2008; Bandini et al. 2010; Emond et al. 2010) and fruits (Lukens and Linscheid 2008; Martins et al. 2008; Emond et al. 2010), as well as demonstrated preference for crispy/crunchy snack foods (Schmitt et al. 2008). One study reported significantly fewer accepted foods across all food groups in children with ASD (Schreck et al. 2004), while another study reported lower variety of dairy but equivalent variety of other food groups (Shearer et al. 1982). Raiten and Massaro (1986) found no significant difference in food groups consumed, and Herndon et al. (2009) reported increased intake of fruit among children with ASD but equivalent intake of other food groups.

Overall Measure of ES for Feeding Behaviors and Nutritional Intake

Tables 4 and 5 present ES estimates calculated using random effects models. The overall test for heterogeneity of study effect sizes was statistically significant ($Q = 29.4$, $df = 14$, $p = 0.009$) indicating that the random effects model was appropriate. The presences of heterogeneity within subgroups further supported the use of the random effects model.

All studies reported greater levels of feeding concerns associated with ASD, regardless of the type of comparison group or method of assessment. SMD estimates across studies ranged from 0.48 to 1.56 (Fig. 2) and the overall SMD involving all comparison groups was large and statistically significant ($p < 0.001$). Analyses involving individual comparison subtypes suggested medium to large differences in feeding problems, ranging from a SMD of 0.69 (0.19) when the comparison group involved children with DD to 0.97 (0.22) when siblings were compared. The corresponding overall OR involving all comparison groups

Table 2 Description of experimental characteristics and assessment methodology by study

	Study									
	Bandini et al. (2010)	Collins et al. (2003)	Dominick et al. (2007)	Emond et al. (2010)	Herndon et al. (2009)	Johnson et al. (2008)	Lockner et al. (2008)	Luckens and Linsheid (2008)	Martins et al. (2008)	Matson et al. (2009)
Outcomes presented										
Feeding behaviors/Food selectivity	X	X	X	X		X	X	X	X	X
Micronutrient analysis of dietary intake	X			X	X	X	X			
Setting										
Community wide	X	X	X	X	X	X	X	X		X
Diagnostic clinic/Early intervention										
Other										
Feeding measure(s)*										
Standardized questionnaires								X	X	
Estimates of nutritional intake	X			X	X	X	X	X		
Subtypes: Food diary	o				o	o	o	o		
24 h recall										
Food frequency inventory	o			o		o		o		
Study specific questionnaire				X		X	X			X
ASD Diagnostic indicator										
Parent report								X		
ASD rating scale									X	X
Clinical provider				X					X	
ADOS				X		X				
ADI-R	X			X		X				
Not specified									X	
Cognitive functioning/IQ					X ^a	X ^a				
Anthropometric data*										
Weight				X						X
Height				X						X
BMI	X			X	X					

Table 2 continued

	Study										N	% of total studies (17 total)	
	Nadon et al. (2011)	Provost et al. (2010)	Raiten and Massaro (1986)	Schmitt et al. (2008)	Schreck et al. (2004)	Shearer et al. (1982)	Zimmer et al. (2012)						
Outcomes presented													
Feeding behaviors/Food selectivity	X	X	X	X	X		X	X				15	88
Micronutrient analysis of dietary intake				X			X					8	47
Setting													
Community wide	X			X								10	59
Diagnostic clinic/Early intervention		X										5	29
Other							X				X	2	12
Feeding measure(s)*													
Standardized questionnaires					X							3	18
Estimates of nutritional intake			X	X	X		X	X			X	11	65
Subtypes: Food diary			o	o			o					6	35
24 h recall												2	12
Food frequency inventory							o				o	6	35
Study specific questionnaire	X	X	X	X								11	65
ASD Diagnostic indicator													
Parent report													
ASD rating scale								X				3	18
Clinical provider	X	X										5	29
ADOS										X		4	24
ADI-R										X		4	24
Not specified												5	29
Cognitive functioning/IQ				X						X		3	18
Anthropometric data*													
Weight				X				X				4	24
Height				X				X				4	24
BMI				X							X	5	29

* Subheadings may not add up to 100 % due to multiple measures used in a study

^a Data only presented for ASD group

Table 3 Description of participants

	Study									
	Bandini et al. (2010)	Collins et al. (2003)	Dominick et al. (2007)	Emond et al. (2010)	Herdon et al. (2009)	Johnson et al. (2008)	Lockner et al. (2008)	Luckens and Linsheid (2008)	Martins et al. (2008)	Matson et al. (2009)
ASD group										
Sample size	53	107	54	79	46	19	20	68	41	112
ASD diagnosis					X					X
Autistic disorder					45					72
PDD–NOS					1					40
Asperger syndrome										
Age (months)	X	X	X	X	X	X	X	X	X	X
Mean	79.2	96	91.2	6, 15, 24, 38, 54*	55.9	39.2		72.8	85.2	
SD	25.2	43.3	29.8		13.9	8.9		29.8	34.4	
Range		36–216			33–96	24–48	36–60	36–132	36–132	36–192
Gender	X		X		X			X	X	
Male (%)	44 (83 %)		47 (87 %)		44 (96 %)			56 (82 %)	34 (83 %)	
Female (%)	9 (17 %)		7 (13 %)		2 (4 %)			12 (18 %)	7 (17 %)	
Comparison group										
Sample size	53 ^a	331 (DD: 262; SB: 69)	38 ^a	12,901 ^a	31 ^a	15 ^a	20 ^a	40 ^a	55 ^a (TD: 41; SB: 14)	167 ^a
Subtype**										
TD	X			X	X	X	X	X	X	X
DD		X	X							
SB		X							X	X
Age (months)	X	X	X	X	X	X	X	X	X	X
Mean	80.4	DD: 95.8; SIB: 99.4	95.3	6, 15, 24, 38, 54*	59.9	36.4		72.8		
SD	28.8	DD: 50.2; SIB: 45.1	33.1		16.5	9.46		29.8		
Range		DD: 24–216.9; SIB: 24–216				24–48		36–132	TD: 12–48; SIB: 24–132	
Gender	X		X		X			X ^c	X	
Male (%)	45 (78 %)		21 (71 %)		23 (74 %)			20 (50 %)	TD: 23 (56 %); SIB: 7 (50 %)	
Female (%)	13 (22 %)		11 (29 %)		8 (26 %)			20 (50 %)	TD: 18 (44 %); SIB: 7 (50 %)	

Table 3 continued

Study		Naon et al. (2011)	Provost et al. (2010)	Raiten and Massaro (1986)	Schmitt et al. (2008)	Schreck et al. (2004)	Shearer et al. (1982)	Zimmer et al. (2012)	Total sample/N	% of total studies (17 total)
ASD group										
Sample size		48	24	40	20	138	12	22	881	
ASD diagnosis		X			X		X	X	5	29
Autistic disorder					10		12	22	5	29
PDD-NOS					3				3	18
Asperger syndrome					4				1	6
Age (months)		X	X	X	X	X	X	X	17	100
Mean		94.8	51.2	127		99	96	98.4	14	82
SD		30	10.6	52		29	9.6	38.4	13	76
Range		45.6–154.8	36–70		84–120	53–152			11	65
Gender		X	X	X	X	X		X	11	65
Male (%)		44 (92 %)	18 (75 %)	28 (70 %)	20 (100 %)	121 (88 %)		20 (91 %)		
Female (%)		4 (8 %)	6 (25 %)	12 (30 %)		14 (10 %)		2 (9 %)		
Comparison group										
Sample size		48 ^a	24 ^a	34 ^b	18 ^a	298 ^a	12	20 ^a	13,544	
Subtype**										
TD			X	X	X	X	X	X	14	82
DD									3	18
SB		X							3	18
Age (months)		X	X	X	X	X	X	X	15	88
Mean		92.4	51.2	105.6		108	100.8	97.2	13	76
SD		34.8	9.8	57.6			7.2	39.6	11	65
Range		37.2–153.6	36–72		84–120	60–144			8	47
Gender		X ^c	X	X ^c	X	X ^c		X	11	65
Male (%)		20 (42 %)	18 (75 %)	19 (56 %)	18 (100 %)	158 (53 %)		10 (45 %)		
Female (%)		28 (58 %)	6 (24 %)	15 (44 %)		140 (47 %)		12 (55 %)		

TD typically developing, DD other developmental delay, SB siblings

* Longitudinal design

** Subheadings may not add up to 100 % due to multiple groups used in a study

^a Reported matched for age

^b Reported age difference with ASD group

^c Reported higher ratio of males to female in ASD group

Table 4 Effect sizes, 95 % confidence limits and within-group tests for heterogeneity for studies included in the meta-analysis for feeding behavior problems by comparison groups

ASD versus subgroup	Number of contributing studies	Random effects model				Within-groups		
		SMD (SE)	OR	95 % confidence limits		<i>p</i> value	χ^2 test (Q)	<i>p</i> value
				LCL	UCL			
All groups	15	0.89 (0.08)	5.11	3.74	6.97	<0.001		
TD	13	0.94 (0.11)	5.49	3.77	7.98	<0.001	29.9	0.003
SB	3	0.98 (0.22)	5.89	2.73	12.71	<0.001	0.45	0.798
DD	2	0.67 (0.19)	3.36	1.69	6.67	0.001	0.012	0.913

TD typically developing, DD other developmental delay, SB siblings

Table 5 Effect sizes, 95 % confidence limits and within-group tests for heterogeneity for studies included in the meta-analysis for nutritional data

Nutrient	Number of contributing studies	Random effects model				<i>p</i> value
		SMD (SE)	OR	95 % confidence limits		
				LCL	UCL	
Calcium	8	−0.65 (0.29)	0.31	0.11	0.85	0.022
Carbohydrates	7	−0.02 (0.07)	0.97	0.76	1.24	0.810
Energy	6	0 (0.06)	0.99	0.80	1.25	0.995
Fiber	6	0.09 (0.12)	1.18	0.77	1.78	0.448
Iron	7	0.17 (0.20)	1.35	0.66	2.76	0.414
Protein	7	−0.58 (0.25)	0.35	0.14	0.86	0.021
Total fat	6	0.03 (0.06)	1.05	0.84	1.30	0.690
Vitamin A	6	−0.51 (0.35)	0.39	0.11	1.37	0.143
Vitamin C	7	−0.13 (0.19)	0.98	0.52	1.87	0.507
Vitamin D	6	−0.07 (0.19)	0.88	0.45	1.71	0.703
Vitamin E	5	0.05 (0.17)	1.10	0.61	1.98	0.742
Zinc	6	−0.03 (0.09)	0.95	0.69	1.31	0.758

was 5.11 (95 % CI 3.74–6.97), suggesting that the odds of having a feeding problem in children with ASD are 5 times the odds for children without ASD.

Analyses involving nutritional data suggested children with ASD had significantly lower consumption of calcium ($p < 0.05$) and protein ($p < 0.05$) compared to TD peers. No other significant differences in nutrient consumption were detected between groups. Bandini et al. (2010) and Zimmer et al. (2012) also assessed risk of inadequate nutrient intake using the cut point method; both reporting children with ASD were significantly more likely to have inadequacies compared to TD children ($p < 0.03$). Given the small sample of studies, we did not estimate an ES for cut point data.

Sensitivity Analysis, Publication Bias and Reliability of Results

Sensitivity analysis involved visual inspection of confidence intervals for the overall effect size after removing

each study. No study significantly altered the overall mean ES estimates for feeding behaviors or nutrient intake. Visual inspection of the funnel plots indicated no potential publication bias for outcome related to feeding behaviors or analyses involving calcium or protein. Furthermore, the failsafe N analysis indicated that there would need to be 858 published studies with non-significant findings related to feeding behaviors to change the current effect size to non-significant. The failsafe N was 37 for the calcium intake outcome was 33 for the protein intake outcome. This evidence lends credence to the robustness of our findings.

Discussion

This meta-analysis shows a strong association between feeding difficulties and ASD, corroborating anecdotal reports and descriptive studies documenting this trend. While previous reviews summarized the literature, this systematic evaluation of the research base quantifies the

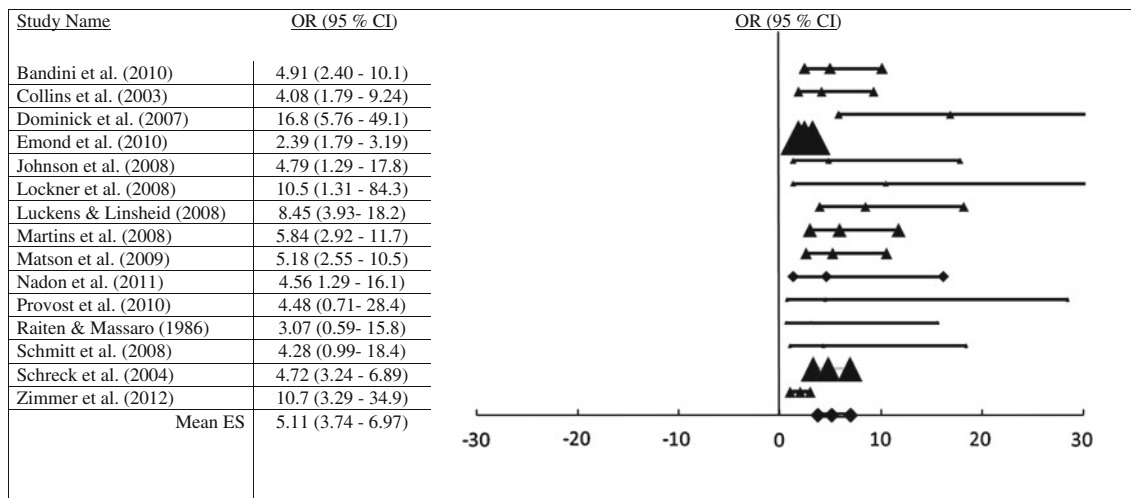


Fig. 2 Forest plot of feeding problems with 95 % confidence intervals

magnitude of effect. By conventional standards, findings reflect a “large” difference in the presence of feeding problems between children with and without ASD, corresponding with an estimated fivefold increase in the odds of having a feeding problem in this population. Higher rates of feeding problems were detected regardless of the make-up of the comparison group or the assessment methodology, providing convergent evidence that feeding problems are more likely to occur in children with ASD. This suggests, at a minimum, assessment of feeding problems in ASD should be included as part of routine screenings in pediatric settings, which would necessitate enhanced awareness among caregivers and practitioners regarding this issue. Encouragingly, the pool of studies included in this review reflects a relative surge in case-control prospective research of feeding problems in ASD, with more than a quarter of the studies published since 2010. Despite greater empirical attention in this area, a closer examination suggests a sizable gap between studies of feeding and other areas of inquiry. For example, even after removing our conservative inclusion criteria, the largest source of articles in the current review, *Journal of Autism and Developmental Disorders*, published only nine studies on feeding problems in ASD between 1980 and 2011; this represents 0.3 % of the 2,485 articles published in the journal over the same time period. Further, only two studies were published in pediatric journals despite the frontline role pediatricians play in screening and identifying health concerns among children with ASD. Given the significant level of feeding concerns associated with ASD and the biological and social significance of healthy eating, greater clinical and research scrutiny in this area are clearly needed to improve assessment methods, increase access to treatment, and develop more definitive conclusions

regarding the impact of aberrant feeding patterns on health and developmental in the ASD population.

When considering the impact of chronic feeding problems, growth and nutrition represent key barometers of health status. Findings from the current review, however, indicate that feeding problems and subsequent nutritional intake deficits do not necessarily translate into greater risk for compromised growth. All seven studies analyzing growth parameters reported no significant difference in height, weight, and/or BMI between children with and without ASD. This parallels nutrient data indicating comparable intake of energy, carbohydrates, and fats when compared to typically developing peers. This suggests, despite increased feeding problems, children with ASD apparently consume enough volume of food to meet gross energy needs and relying exclusively on anthropometric parameters to assess health status may in fact mask underlying nutritional deficits. It may also explain why feeding problems are often overlooked in relation to other area of clinical concern in the ASD population, since failure to thrive or a declining growth velocity are the standard nutritional health indicators (WHO 2006) that trigger clinical attention in pediatric settings (Ledford and Gast 2006). Closer examination of nutrient intake, however, indicates significant specific deficits (lower intake of calcium and protein) and a higher number of nutritional deficits overall among children with ASD. These patterns may well place this population at risk for long-term medical complications not captured by broad anthropometrics or energy intake. For example, lower levels of calcium, compounded by the increased need for this nutrient during childhood to promote growth of bones, may portend risk of osteomalacia and osteoporosis. This assertion is consistent with findings indicating decreased bone cortical thickness

in a group of 75 boys with ASD when compared to peers, highlighting the need to investigate the calcium intake and bone growth in children with ASD, as well as identify possible etiologies (Hediger et al. 2007). Together, the available evidence suggests the need to look beyond gross anthropometric parameters, such as incorporating idiosyncratic analysis of nutritional intake as part of routine medical care in ASD. It will also be important to determine the long-term health burden associated with atypical patterns of intake on a population level, particularly high consumption of snack and fats in ASD, which may portend increased risk for diet-related diseases (e.g., obesity, cardiovascular disease) in adolescence or adulthood.

Two candidates for explaining reduced nutrient intake in ASD are food selectivity and/or elimination diets (e.g., the GFCF diet). Only three studies in the current review, however, specifically investigated the relationship between restricted patterns of intake and nutritional status. Herndon et al. (2009) reported fewer servings of dairy and that this relationship remained after excluding children following a GFCF diet. Zimmer et al. (2012) excluded children on elimination diets and still reported that selective eaters with ASD had lower intake of calcium, vitamin B12, and vitamin D, compared to non-selective eaters with ASD and lower intake of protein, calcium, vitamin A, and vitamin D, compared with typically developing peers. Finally, Bandini et al. (2010) reported children with ASD experienced more nutrient inadequacies than typically developing children, a finding that persisted after excluding children on special diets. Together, there is evidence suggesting that nutritional issues associated with ASD may be related to the patterns of food selectivity beyond what could be attributed to parent-mediated dietary manipulations. Going forward, it will be important to control for the use of vitamin/mineral supplements, which may mask an even greater risk of compromised dietary status among children with ASD. Provisional evidence suggests higher use of supplements among caregivers concerned about increased levels of food selectivity or food refusal (Yu et al. 1997), and parents of children with ASD may be more likely to try dietary supplementation in general (Lockner et al. 2008).

The combination of increased feeding problems and nutritional concerns raises important questions regarding the use (and possible detrimental impact) of dietary manipulations in the ASD population. Many of these diets (e.g., the GFCF) eliminate dairy proteins, placing additional restrictions on a population vulnerable for lower calcium intake, and provisional evidence suggests that this may lead to greater deficits in bone development among children with ASD (Hediger et al. 2007). Elimination diets also target starches and snack foods often identified as preferred foods among children with ASD, which may increase the risk for weight loss and further nutritional

deficits (Lukens and Linscheid 2008). With this in mind, caregivers should employ utmost caution when deciding to pursue this form of treatment. At a minimum, families wishing to pursue a possible dietary intervention should do so under the guidance of a healthcare professional (e.g., registered dietitian) who can assess the impact of further restrictions on a child's nutritional status and work to ensure the child's nutritional needs are met during the intervention. Similarly, untested interventions that may secondarily affect nutritional status, such as chelation therapy, could compound an already risky situation by further reducing the bioavailability of key nutrients, such as calcium. Clearly, such potential iatrogenic effects should be carefully investigated prior to recommending any treatment. To assist caregivers with making an informed decision, pediatric practitioners must screen for preexisting feeding concerns, highlight the tenuous empirical support for diet modification as treatments of ASD and review potential consequences (e.g., further nutritional deficits, stigmatization, diversion of treatment resources; Mulloy et al. 2010) and barriers (e.g., resources to purchase specialized foods, strategies for ensuring dietary compliance; Elder 2008) associated with dietary interventions. Additional research will also be needed to more clearly elucidate the impact of dietary manipulations on growth, nutrition, and family resources.

The higher rate of feeding concerns in ASD also emphasizes a subsequent need to identify and disseminate empirically-supported treatments for feeding problems associated with ASD. At this time, behavioral intervention represents the only empirically supported treatment for pediatric feeding disorders Sharp et al. (2010) and there is provisional evidence that these benefits apply to children with ASD. With this said, support for behavioral treatment to expand dietary variety has primarily been documented at day-treatment or inpatient feeding programs (Laud et al. 2009; Sharp et al. 2011). Unfortunately, few inpatient and day-treatment programs exist, which curtails adequate access to care. Given the need for feeding intervention in this population, an important goal moving forward will be to develop additional treatment options, such as organizing disciplines involved in providing care along clinical service lines and expanding training and educational opportunities for community providers regarding behavioral strategies for targeting food selectivity. It will also be important to determine whether intervention to address food selectivity in ASD can be adapted for delivery through less intensive methods of service delivery, such as outpatient treatment, group therapy, or caregiver training.

This review also highlights important areas for future research to enhance understanding of feeding problems and nutrient status in ASD (Table 6). More detailed diagnostic characterization continues to be needed to better define

Table 6 Summary of key recommendations for clinical and research activities for feeding and ASD

In clinical settings, healthcare providers are encouraged to:	
1.	Include assessment of feeding problems as part of routine medical evaluations
2.	Screen for nutritional deficits/excesses in addition to measurement of gross anthropometric parameters
3.	Engage in caregiver education regarding tenuous empirical support for diet modification as treatment of ASD
4.	Review potential consequences of pursuing an elimination diet with consideration to the child's unique feeding and nutritional presentation
To enhance the literature moving forward, researchers should seek to:	
1.	Include detailed diagnostic characterization (e.g., ADOS, ADI) to confirm ASD status
2.	Further develop assessment methods to quantify feeding problems and nutrient status
4.	Identify and disseminate empirically-supported treatments for feeding problems in ASD
5.	Determine the long-term health burden associated with atypical patterns of intake on a population level (e.g., obesity, cardiovascular disease), as well as the relationship with other areas of functioning (e.g., quality of life, gastrointestinal issues)

samples of children with ASD. The dearth of studies in this review that provided a well characterized sample utilizing diagnostic measures, like the Autism Diagnostic Observation Schedule (ADOS; Lord et al. 2000) and Autism Diagnostic Interview (ADI; Lord et al. 1994) that have been standards of best practice in research for over a decade, is striking and further emphasizes the limitations of our knowledge of feeding profiles in ASD. Without standardized measures across samples, questions regarding the relationship between ASD symptomatology and feeding behaviors remain unanswered. The relationship of atypical feeding and intellectual status in children with ASD also remains unclear given the lack detailed psychometric data, but represents an important focus for future research.

There is also a clear need to develop a frontline feeding screening tool to support research which can also be efficiently applied during medical appointments. Outcomes summarized in this review primarily involved study-specific single-item measures, which limit conclusions regarding prevalence and topography that can be drawn across studies. Specifically, prevalence rates varied depending on the content of the item or assessment method, with estimates as high as 95 % of a sample describe as resisting trying new foods (Lockner et al. 2008). This could explain—at least in part—the high variability in prevalence estimates cited by Ledford and Gast (2006). Without increased standardization in the measurement of feeding concerns, the true prevalence of feeding concerns in ASD populations remains unknown at this time. In addition, definitive conclusions regarding the exact

nature of feeding problems associated with ASD remain elusive. The current study collapsed food selectivity and food refusal under the larger umbrella of feeding problems due to the heterogeneity of item content, which reflects a more global need to develop consensus regarding the definition of specific feeding concerns (e.g., food refusal vs. food selectivity) in the pediatric feeding disorder literature. Increased diagnostic clarity would, in turn, aid in the development of standardized feeding measures.

Finally, findings also raise important questions regarding how best to measure the nutritional status of children with ASD. Idiosyncratic food choices among selective eaters will likely result in different patterns of nutrient deficiencies based on the core foods that comprise an individual's diet, which may explain conflicting results among past reports. We recommend that studies present data regarding overall group analysis of nutrient intake, as well as an individual analysis regarding number of deficiencies using the cut point method. Research would also benefit from increased standardization in the measurement of nutritional intake (e.g., food diary, 24 h recall), consistent documentation of anthropometric data, and long-term assessment regarding the stability of dietary patterns over time. Finally, researchers are also encouraged to extend the net of inquiry to include additional related outcomes, including quality of life, family functioning, relationship with gastrointestinal issues, impact on developmental and cognitive status, and etiological factors influencing dietary preference in ASD.

Conclusion

Our results confirm that children with ASD have more feeding problems compared with peers. We also found a trend of lower intake of calcium and protein on a population level, and higher levels of nutritional inadequacies in ASD, detected via idiosyncratic analyses using the cut point method. Provisional data suggest food selectivity contributes to nutritional concerns related to ASD outside of parent-mediated restrictions. Clinicians are encouraged to increase screening for feeding concerns in children with ASD and to use this information when counseling caregivers interested in pursuing an elimination diet.

Conflict of interest This was an unfunded study and no member of the research team has a conflict of interest.

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