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Impact Of 100% Fruit Juice Consumption On Diet And Weight Status Of Children: An Evidence-Based Review

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Abstract

Consumption of 100% fruit juice remains controversial for its potential adverse impact on weight and displacement of essential foods in the diets of children. A systematic review of the literature published from 1995–2013 was conducted using the PubMed database to evaluate associations between intake of 100% fruit juice and weight/adiposity and nutrient intake/adequacy among children of 1 to 18 years of age. Weight status outcome measures included body mass index (BMI), BMI z-score, ponderal index, obesity, weight gain, adiposity measures, and body composition. Nutrient outcome measures included intake and adequacy of shortfall nutrients. Data extraction and analysis was conducted according to the Academy of Nutrition and Dietetics Evidence Analysis Process. Twenty-two studies on weight status provided evidence that did not support an association between 100% fruit juice consumption and weight/adiposity in children after controlling for energy intake. Limited evidence from eight studies suggests that children consuming 100% fruit juice have higher intake and adequacy of dietary fiber, vitamin C, magnesium, and potassium. Differences in methodology and study designs preclude causal determination of 100% fruit juice as sole influence of weight status or nutrient intake/adequacy of shortfall nutrients. In context of a healthy dietary pattern, evidence suggests that consumption of 100% fruit juice may provide beneficial nutrients without contributing to pediatric obesity.

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Consumption of 100% fruit juice remains controversial for its potential adverse impact on weight and displacement of essential foods in the diets of children. A systematic review of the literature published from 1995–2013 was conducted using the PubMed database to evaluate associations between intake of 100% fruit juice and weight/adiposity and nutrient intake/adequacy among children of 1 to 18 years of age. Weight status outcome measures included body mass index (BMI), BMI z-score, ponderal index, obesity, weight gain, adiposity measures, and body composition. Nutrient outcome measures included intake and adequacy of shortfall nutrients. Data extraction and analysis was conducted according to the Academy of Nutrition and Dietetics Evidence Analysis Process. Twenty-two studies on weight status provided evidence that did not support an association between 100% fruit juice consumption and weight/adiposity in children after controlling for energy intake. Limited evidence from eight studies suggests that children consuming 100% fruit juice have higher intake and adequacy of dietary fi er, vitamin C, magnesium, and potassium. Differences in methodology and study designs preclude causal determination of 100% fruit juice as sole infl of weight status or nutrient intake/adequacy of shortfall nutrients. In context of a healthy dietary pattern, evidence suggests that consumption of 100% fruit juice may provide benefi nutrients without contributing to pediatric obesity.

Keywords 100% fruit juice, weight, adiposity, nutrient intake, nutrient adequacy, children, Evidence Analysis Library

INTRODUCTION

The severity of the childhood obesity epidemic and its potential health consequences have led scientists and clinicians to look for immediate and simple solutions. A common approach to solve this complex problem is to identify and target single foods for elimination from the diet. With the exception of low-fat or fat-free white fl milk, all beverages containing sugar in any form, whether naturally occurring or added, including 100% fruit juice, have been under attack by some scientists, clinicians, and the general public. One hundred percent fruit juice has been referred to as a nutrient-poor beverage that has contributed to the obesity epidemic in children, and there are recommendations that it should be limited or omitted from the diets of children (Wojcicki and Heyman, 2012). However, results from studies examining consumption of 100% fruit juice and obesity have been contradictory, yet generally supported no association.

The Dietary Guidelines for Americans (United States Department of Agriculture and United States Department of Health and Human Services, 2010) defined eight ounces of 100% fruit juice,

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but not other types of fruit beverages, including fruit drinks or juice cocktails, as an equivalent serving to whole fruit. With the exception of dietary fi 100% fruit juice retains many of the nutrients, phytochemicals, and antioxidants of its whole fruit counterpart (Ruxton et al., 2006; Crowe and Murray, 2013). According to a recently published systematic review, multiple plausible mechanisms exist to support a positive relationship between consumption of specifi types of 100% fruit juice and human health or disease prevention (Hyson, 2015). Thus, 100% fruit juice is a nutrient-dense food with potential to benefi human health, including maximizing growth and development in children (Rampersaud, 2007). In addition, when consumed in the context of a total diet pattern guided by the Dietary Guidelines for Americans (United States Department of Agriculture and United States Department of Health and Human Services, 2010), 100% fruit juice may help individuals and populations meet the dietary reference intakes for nutrients, especially micronutrients (United States Department of Agriculture National Agricultural Library, 2015). The purposes of this review were to evaluate associations between consumption of 100% fruit juice and weight status or adiposity, as well as to assess nutrient intake and nutrient adequacy among children who consumed 100% fruit juice.

METHODS

Evidence Analysis Team and Process

The workgroup included six registered dietitians or registered dietitian – nutritionists with clinical or research experience. A thorough recruitment procedure was undertaken with requests for participation posted on the Academy of Nutrition and Dietetics' website and via email correspondence, which targeted all Academy members, Academy Dietetic Practice Groups, and known experts in the field. The applicants were rubric-scored using a set of quantitative and qualitative criteria and potential for conflict of interest. All workgroup members signed a conflict of interest disclosure form as well as declared verbally any conflicts of interest prior to the start of each workgroup meeting. A trained and experienced project manager facilitated these meetings with the assistance of a lead analyst. A complete description of the Evidence Analysis Process is available at the Academy's Evidence Analysis Library (EAL) website (Academy of Nutrition and Dietetics, 2014a). Briefly, articles meeting the inclusion criteria were abstracted using the EAL Data Extraction Tool and reviewed for accuracy by EAL analysts. A summary evidence table was constructed for each question along with narrative summaries of evidence.

Literature Search and Application of Inclusion/Exclusion Criteria

Full-length studies meeting the eligibility criteria included human studies that were published in English from 1995 to 2013 and reported outcomes related to weight or adiposity measures and dietary intake among healthy, free-living children one to 18 years of age consuming 100% fruit juice. To evaluate the published literature comprehensively, no preference was given to the type of study design. For a study to be included in this systematic review, the US Food and Drug Administration's following defi ion of 100% fruit juice was used: "Juices directly expressed from a fruit or vegetable (i.e., not concentrated and reconstituted) shall be considered to be 100% juice and shall be declared as 100% juice" (Department of Health and Human Services, 2013). For this review, the above defi n was expanded to include juices from concentrate, which were reconstituted to their original volume. Additional inclusion criteria were a minimum of 10 participants in the study and a drop-out rate of under 20% with at least one adiposity measure (body mass index [BMI], BMI percentile, rate of weight gain, BMI z-score, body composition, body fat, waist-to-hip ratio, and waist circumference) or one nutrient of interest (dietary fi vitamins A, C, D, or E, calcium, iron, magnesium, or potassium) reported. Articles were excluded from consideration if it was not clear that 100% fruit juice was used in the study, the participants were outside the specified age range, or if the article appeared in non-peer-reviewed journals; only full-length articles were considered.

The workgroup members and lead analysts assessed all studies identified in the PubMed search for relevance. Analysts and lead analysts who worked on data extraction then reassessed these articles for eligibility. This systematic process yielded 22 studies that examined the relationship between weight status or adiposity and consumption of 100% fruit juice (Fig. 1) and 10 studies that examined nutrient intake or adequacy and consumption of 100% fruit juice (Fig. 2). The Academy's online data extraction tool was used to extract and store data from the research articles. Trained analysts or methodology experts extracted the following data from each eligible research article: title, year and journal of publication, study design, intervention and control groups (if applicable), details of interventions (type of intervention, who delivered the intervention, duration of intervention, and mode of intervention) (if applicable), confounding variables considered in the analysis, and outcomes of interest (i.e. weight/adiposity outcomes or measures or nutrients of interest). A second reviewer (lead analyst) verified the accuracy of data entered into the data extraction tool.

Data Analysis

Data were collected from each article with the intention of carrying out meta-analyses on outcomes associated with consumption of 100% fruit juice and weight status or adiposity as well as nutrient intake and nutrient adequacy among children consuming 100% fruit juice. However, the following study characteristics prevented the calculation of a reliable pooled

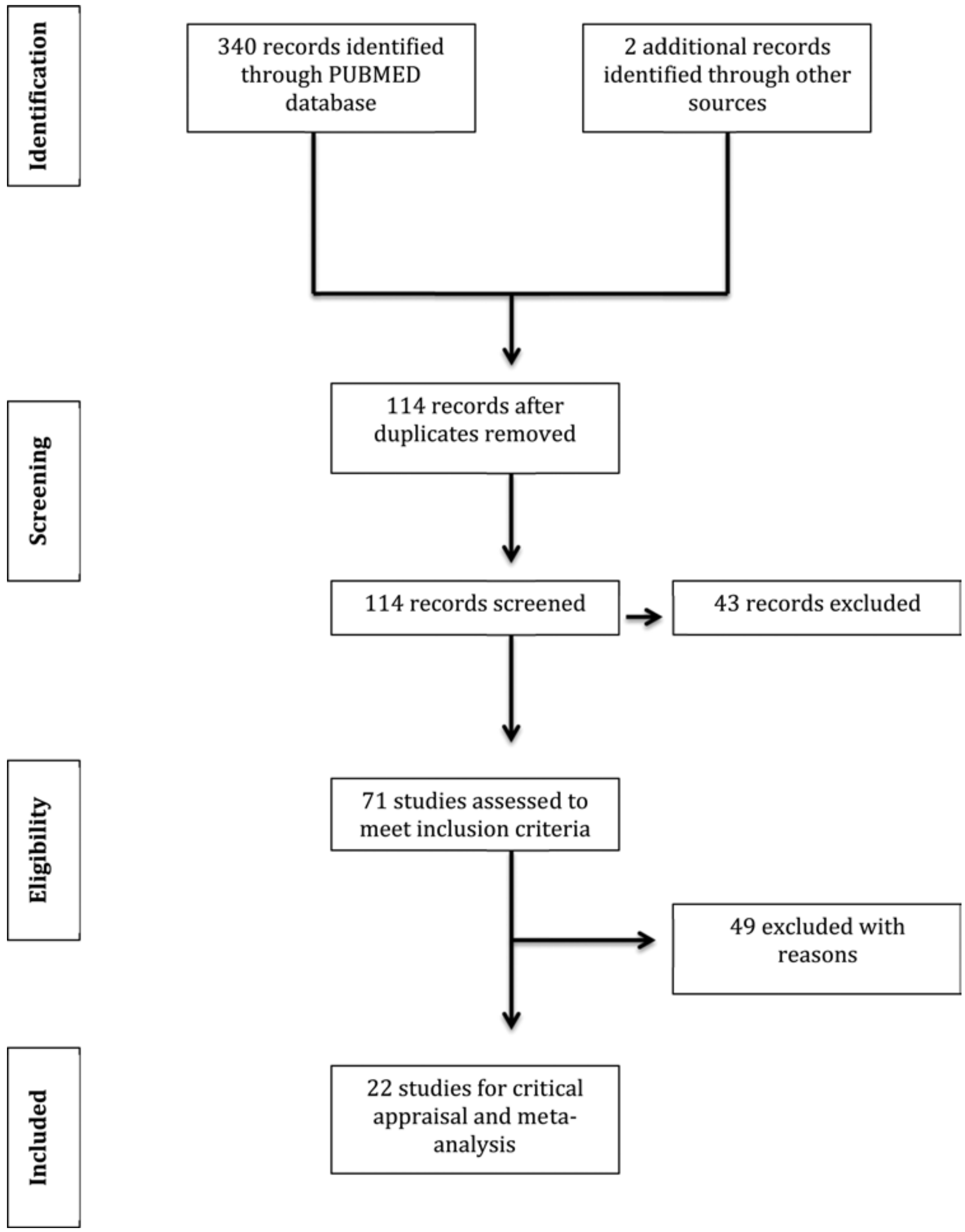

Figure 1 Search strategy flow diagram for research evaluating associations between 100% fruit juice intake and weight status or adiposity among children.

effect size of the relationship between 100% fruit juice intake and outcomes: fruit juices examined were inconsistent across studies, method by which intake was specified or measured was inconsistent (e.g. intake change versus intake at one point in time, method of intake assessment, and intake level grouped according to different criteria), and outcome measures were reported in incommensurate ways. Thus, patterns of association between intake of 100% fruit juice and outcome measures were assessed qualitatively.

Of particular concern among research reviewed was adjustment for intake of other foods and macronutrients within the diet. With observational research, adjustment for potential or known confounding variables is critical for accurate parameter estimates. The lack of consistency in confounders controlled for (or, more critically, the lack of any adjustment in several studies) rendered the effort to compute a single meaningful pooled effect size impossible. Subgroup meta-analyses were used, however, to illustrate the importance of controlling for one critical confounder: energy intake. For weight status outcomes, a random effects meta-analysis of reported or computed (when data were available) weight status log transformed odds ratios was carried out to illustrate the importance of model adjustment. STATA 13.0 was used and methods for computing statistical measures followed those described in the *Cochrane Handbook* (The Cochrane Collaboration, 2011).

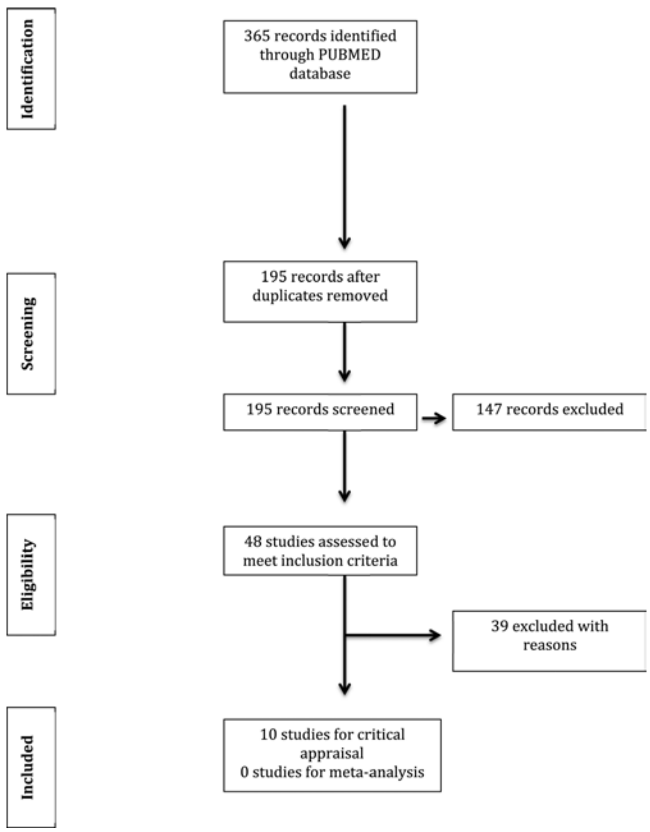

Figure 2 Search strategy flow diagram for research evaluating associations between consumption of 100% fruit juice and nutrient intake and adequacy among children.

Development of Conclusion Statements

Evidence summary and conclusion statements on the impact of 100% fruit juice consumption on diet and weight status of children were drafted by the workgroup and lead analyst based on evidence analysis after completion of the data extraction process. The *EAL Manual for Grading the Strength of the Evidence* (Academy of Nutrition and Dietetics, 2014b, 2014c) was used for grading the conclusion statements according to the following grades: Grade I (good/strong), grade II (fair), grade III (limited/weak), grade IV (expert opinion only), or grade V (grade not assignable).

ASSOCIATION BETWEEN INTAKE OF 100% FRUIT JUICE AND WEIGHT STATUS OR ADIPOSITY

Research Reviewed

Among the 22 studies meeting the inclusion criteria, 12 were cross-sectional (Dennison et al., 1997, 1999; Skinner et al., 1999; Nelson et al., 2006; O' Connor et al., 2006; LaRowe et al., 2007; Nicklas et al., 2008; O' Neil et al., 2010; Makkes et al., 2011; O' Neil et al., 2011a; Danyliw et al., 2012; Wang et al., 2012). Eight were prospective cohort studies (Alexy et al., 1999; Skinner et al., 2001; Field et al., 2003; Berkey et al., 2004; Newby et al., 2004; Streigel-Moore et al., 2006; Libuda et al., 2008; Fiorito et al., 2009). One retrospective cohort design was evaluated (Welsh et al., 2005) along with one time-series study (Taber et al., 2012).

Weight Status and Energy Adjustment

Ten studies reported information on 16 separate groups sufficient to compute odds ratios of being either overweight or obese comparing the highest fruit juice consumers with the lowest consumer group (Dennison et al., 1997; Skinner et al., 1999; Welsh et al., 2005; Nelson et al., 2006; Nicklas et al., 2008; O' Neil et al., 2010; Makkes et al., 2011; O' Neil et al., 2011a; Wang et al., 2012; Danyliw et al., 2012). Definitions of the highest and the lowest consumption groups varied by study (Table 1). Where the definition of weight status group differed from current definitions of Center for Disease Control and Prevention (2015), the BMI percentile cutoff is reported. The results of the meta-analysis of study groups sub-grouped by energy intake is presented in Fig. 3.

Variations in intake measurement and definition of fruit juice group rendered the estimate of pooled effect untrustworthy, so the subgroup meta-analysis was used primarily to identify patterns among findings. However, a critical pattern is evident in Fig. 3. Statistically significant differences between higher and lower fruit juice consumers in terms of weight status were reported *only* in studies that did not adjust for total energy intake. None of the 11 comparisons that adjusted for total energy intake reported a statistically significant difference between higher and lower fruit juice consumers in terms of weight status. This indicates that consumption of 100% fruit juice has no independent effect on weight status apart from energy intake. Notably, neither of the two earliest studies that were evaluated adjusted for total energy intake, yet both reported the highest odds ratios (Dennison et al., 1997; Skinner et al., 1999).

Body Mass Index and Ponderal Index

Body mass index (weight [kg]/height [m]^2), a predominant measure of overweight and obesity used in children, was reported in 18 studies (Dennison et al., 1997, 1999; Alexy et al., 1999; Skinner et al., 1999; Skinner and Caruth, 2001; Berkey et al., 2004; Newby et al., 2004; Welsh et al., 2005; Nelson et al., 2006; O' Connor et al., 2006; Stiegel-Moore et al., 2006; LaRowe et al., 2007; Nicklas et al., 2008; O' Neil et al., 2010, 2011a; Makkes et al., 2011; Danyliw et al., 2012; Wang et al., 2012).

The majority (15/18, 83%) of studies found no significant association between 100% fruit juice intake and BMI. Only three studies reported a positive relationship with consumption of 100% fruit juice and BMI, BMI percentile, or the likelihood

Table 1 Studies on weight status or adiposity and 100% fruit juice consumption among children

Study population	Study design	Type of 100% fruit juice	Measure of consumption	Outcomes	References
German *n* D 205 (49% F) 3 – 5 years Race: NR	Prospective cohort	Not specified	3-d weighed food record Oz./d categorized as less than 12 oz./d or >12 oz./d	BMI D NS	Alexy et al., 1999
USA *n* D 10,769 (57% F) 9 – 14 years Race: White, Black, Hispanic, Asian	Prospective cohort	Orange, apple, "other"	Semi-quantitative FFQ Serving size: Can, glass, bottle or cup tailored to the particular beverage	BMI D NS	Berkey et al., 2004
USA *n* D 16,886 (68% F) 9 – 14 years Race: NR	Prospective cohort	Not specified	FFQ with serving sizes based on USDA National Nutrient Database for ages 9 – 18 years	BMI z-score Females D *P* D 0.003 Males D NS	Field et al., 2003
USA *n* D 170 (100% F) 5 – 15 years Race: White, Non-Hispanic	Prospective cohort	Not specified	(3) 24-h dietary recalls Servings/d based on 8-oz. serving size	Fat mass D NS	Fiorito et al., 2009
German *n* D 244 (49% F) 9 – 18 years Race: NR	Prospective cohort	Not specified	3-day weighed diet record (g/d)	BMI z-score Girls D *P* < 0.05 Boys D NS Fat Mass D NS	Libuda et al., 2008
USA *n* D 2371 (100% F) 9 – 19 years Race: White, Black	Prospective cohort	Not specified	(1) 3-day diet record* (g/d)	BMI D NS	Striegel-Moore et al., 2006
USA *n* D 1345 (50% F) 2 – 5 years Race: White, Black, Hispanic, Asian, Other	Prospective cohort cross-sectional	Not specified	FFQ with 84 foods and beverages (oz./d)	BMI D NS	Newby et al., 2004
Canadian *n* D 10,038 (% F NR) 2 – 18 years Race: NR	Cross-sectional	Not specified	(1) 24-h dietary recall (g/d)	BMI D NS	Danyliw et al., 2012
USA *n* D 168 (% F NR) 2 years (n D 94) 5 years (n D 74) Race: White (97%)	Cross-sectional	Not specified	7-d diet record oz./d categorized as less than 12 oz./d or > 12 oz./d	BMI 2: 75th percentile D NS BMI 2: 90th percentile D *P* <0.05 PI (2 years, 5 years) D *P* < 0.05	Dennison et al., (1997
USA *n* D 163 (48% F) 2 years (n D 111) 5 years (n D 107) Race: White	Cross-sectional	Apple, orange, grape, "other"	(7) 24-h dietary recalls (1) 7-d diet record (oz./d)	BMI D *P* < 0.05 for 100% apple juice PI D *P* < 0.05	Dennison et al., 1999
USA *n* D 1334 (45% F) 2 – 5 years (n D 541) 6 – 10 years (n D 793) Race: White, Black, Mexican-American, Other	Cross-sectional	Not specified	(1) 24-h dietary recall (g/d)	BMI D NS	LaRowe et al., 2007
Guatemalan	Cross-sectional	Not specified	One day intake using a	BMI D *P* < 0.05	Makkes et al., 2011

n D 356 (% F NR) 8 – 10 years Race: Mestizos (mixed ethnicities)	pictorial workbook and dietitian-assisted recall (g/d)

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Table 1 Studies on weight status or adiposity and 100% fruit juice consumption among children *(Continued)*

Study population	Study design	Type of 100% fruit juice	Measure of consumption	Outcomes	References
USA *n* D 526 (45% F) 2 – 4 years Race: White, Black, Hispanic, Asian, Other	Cross-sectional	Not specified	Parents were asked questions about diet Servings/d or week with serving sizes not specified	BMI D NS	Nelson et al., 2006
USA *n* D 3618 (% F NR) 2 – 11 years Race: White, Black Mexican-American, Asian	Cross-sectional	Not specified	(1) 24-h dietary recall Oz./d categorized as 0 oz./d, < 6 oz./d, 6 – 12 oz./d, or >12 oz./d	BMI D NS BMI z-score D NS Fat Mass D NS	Nicklas et al., 2008
USA *n* D 1160 (50% F) 2 – 5 years Race: White, Black, Mexican-American, Asian	Cross-sectional	Not specified	(1) 24-h dietary recall (oz./d)	BMI D NS	O' Connor et al., 2006
USA *n* D 3939 12 – 18 years Race: White, Black, Hispanic, Other	Cross-sectional	Not specified	(1) 24-h dietary recall Oz./d categorized as 0 oz./d, <6 oz./d, 6 – 12 oz./d, or >12 oz./d	BMI D NS BMI z-score D NS	O' Neil et al., 2010
USA *n* D 250 (% F NR) 2 – 18 years Race: White, Black, Hispanic, Asian	Cross-sectional	Orange	(2) 24-h dietary recalls Oz./d categorized as: 0 oz./d, >0 oz./d	BMI D NS Fat mass D NS	O' Neil et al., 2011a
USA *n* D 2 (49% F) 2 – 6 years Race: White	Cross-sectional	Not specified	In-home interviews including (2) 24-h dietary recalls and (2) diet records (oz./d)	BMI D NS PI D $P < 0.05$	Skinner et al., 2001
USA *n* D 105 (48% F) 2 – 3 years Race: White	Cross-sectional	Not specified	In-home interviews including (2) 24-h dietary recalls and (2) diet records with one weekend day Oz/d categorized as <12 oz./d or >12 oz./d	BMI D NS PI D NS	Skinner et al., 1999
USA *n* D 13,971 (50% F) 4 – 18 years Race: White, Black, Mexican-American, Asian	Cross-sectional	Orange	(2) 24-h dietary recalls Oz./d categorized as 0 oz./d, <4.1 oz./d, 4.1 to 7.5 oz./d, or >7.5 oz./d	BMI D NS Fat mass D NS	Wang et al., 2012
USA *n* D 272,044 (49% F) 14 – 18 years Race: White, Black, Hispanic, Other	Time series design	Not specified	Youth risk behavior survey using servings/d with serving size not specified	BMI z-score Females D $P < 0.05$ Males D NS	Taber et al., 2012
USA *n* D 10,904 2 – 3 years Race: White, Black, Other	Retrospective cohort	Orange, not specified	FFQ with serving size defined by parent	BMI D NS	Welsh et al., 2005

F, female; NR, not reported; NS, not significant ($P > 0.05$); g/d, grams/day.

*Although eight three-day diet records were collected over the course of 10 years, the regression models were built on one visit where a three-day diet record was collected.

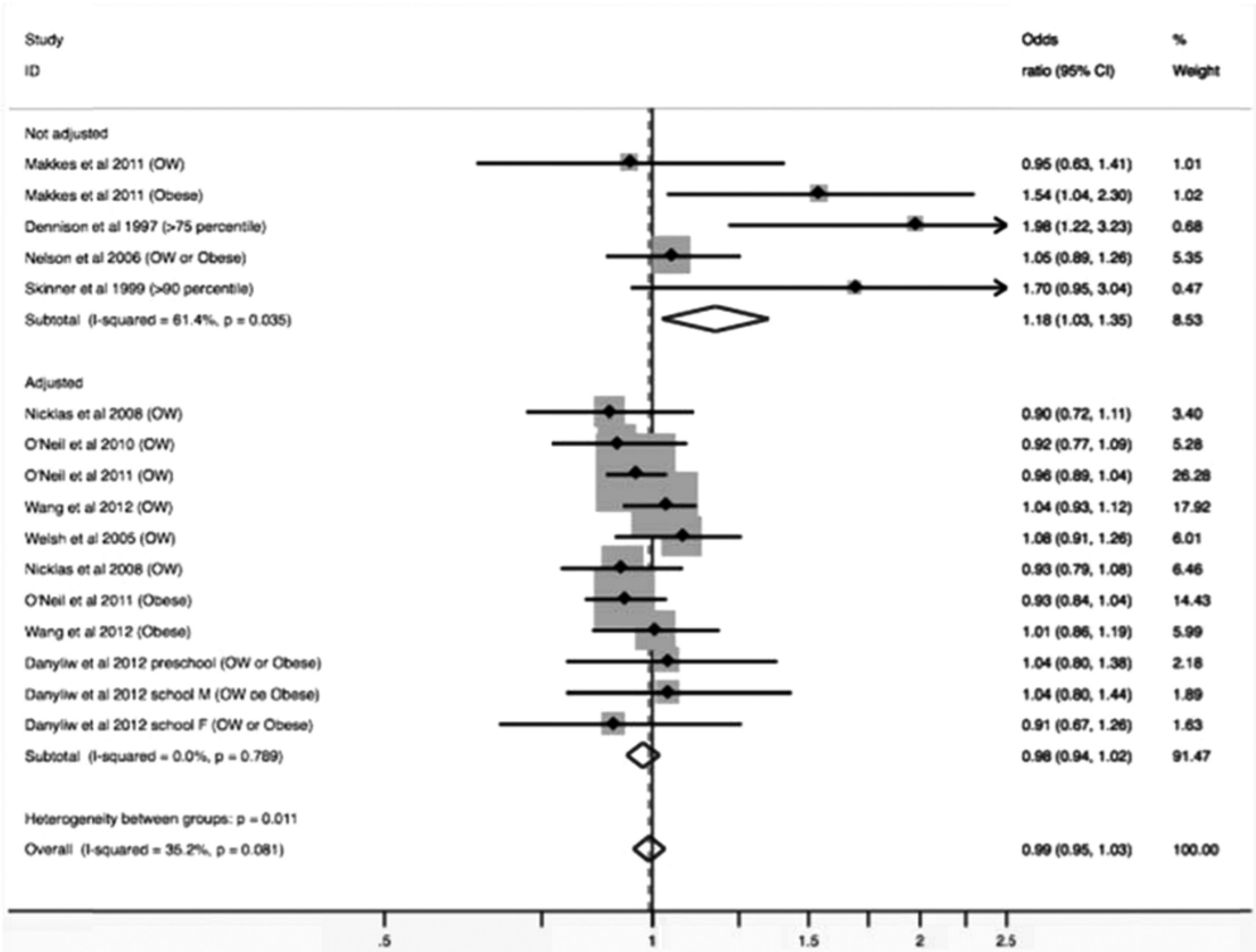

Figure 3 Odds ratio of overweight or obese (or both): highest versus lowest 100% fruit juice consumers sub-grouped by energy intake adjustment.

of being obese in children (Dennison et al., 1997, 1999; Makkes et al., 2011). These studies had significant limitations. Only one of the three adjusted for total energy intake (Dennison et al., 1999); however, the effect size was minimal (e.g. every additional gram of 100% apple juice consumed per day was associated with a 3/1000th of a point higher BMI). It is also important to note that each of these three studies were small regional studies (combined $n < 360$) with limited racial/ethnic and socioeconomic diversity among participants. Thus, the findings reported therein cannot be generalized to a larger, more diverse population. None of the large nationally representative studies reported any association between intake of 100% fruit juice and BMI (Newby et al., 2004; Welsh et al., 2005; O' Connor et al., 2006; Striegel-Moore et al., 2006; LaRowe et al., 2007; Nicklas et al., 2008; O' Neil et al., 2010, 2011a; Danyliw et al., 2012; Wang et al., 2012).

Ponderal index (PI) (weight [kg]/height [m]^3) is another measure of overweight and obesity used in children. Four studies examined the association of 100% fruit juice consumption and weight status using PI, yet results were confl (Dennison et al., 1997, 1999; Skinner et al., 1999, 2001). For example, Dennison et al. (1997) reported that children aged two (n D 15) and fi (n D 4) years who consumed at least 12 ounce of 100% fruit juice per day were more likely (P D 0.0001) to be in the 2:90th PI percentile than children of the same age who consumed less than 12 ounce of 100% fruit juice daily. However, in a similar study of slightly younger children aged two and three years old (n D 105), Skinner et al. (1999) reported no association between PI and consumption of 100% fruit juice. Neither study controlled for total energy intake. In a study that did control for total energy intake (minus energy from 100% fruit juice), Dennison et al. (1999) reported that PI was signifi ($P < 0.002$) related to consumption of 100% apple juice in a small sample of children (n D 104 apple juice consumers) aged two and fi e years; however, the effect size was very small (b D 0.0054), indicating that for every additional gram of 100% apple juice consumed per day on average, PI was associated with a 5/1000th of a point higher. The authors found no association with PI and consumption of other types of 100% fruit juice. In contrast, a prospective cohort study of children aged between two and three years (n D 72) reported a small but statistically signifi (P D 0.05, b D − 0.065) inverse relationship between 100% fruit juice consumers and PI ($P <$ 0.05) after adjusting for energy intake (Skinner et al., 2001). These results suggest that higher longitudinal intake of 100% fruit

Table 2 Studies on dietary nutrient intake and adequacy of shortfall nutrients and 100% fruit juice consumption among children

Study population	Study design	Type of 100% fruit juice	Measurement of consumption	Intake	Adequacy	Reference
USA *n* D 168 (47% F) 2 years (n D 94) 5 years (n D 74) Race: NR	Cross-sectional	Apple, orange, mixed fruit juice, grape, pear, pear – apple	Servings/d	***P*** D 0.01 Vitamin C NS Calcium Potassium Vitamin A	NA	Dennison et al., 1998
USA 6 – 11 years male (n D 1073) 6 – 11 years female (n D 1051) 12 – 19 years male (n D 2,251) 12 – 19 years female (n D 2263) Race: NR NHANES 1999 – 2002; CSFII 1994 – 96/1998	Cross-sectional	Not specified	g	***P*** D 0.01 6 – 11 y males, calcium ***P*** D 0.05 6 – 11y females, calcium 12 – 19 y males, calcium NS 12 – 19 y females, calcium	NA	Forshee et al., 2006
USA *n* D 1334 (45% F) 2 – 5 years Race: White, Black, Mexican-American, Other NHANES 2001 – 2002 n D 1992 FJ cluster D 73	Cross-sectional	Not specified	(1) 24-h dietary recall g/d	***P*** < 0.0001 Vitamin C Vitamin A ***P*** < 0.05 Calcium Iron NS Fiber	NA	LaRowe et al., 2007
USA *n* D 3618 (% F NR) 2 – 11 years Race: White, Black Mexican-American, Asian NHANES 1999 – 2002	Cross-sectional	Not specified	(1) 24-h dietary recall Oz./d categorized as 0 oz./d, < 6 oz./d, 6 – 12 oz./d, or > 12 oz./d	***P*** < 0.001 Potassium Vitamin C Magnesium (for intakes > 6 oz./d) Iron (for intakes > 6 oz./d) NS Calcium Phosphorus Vitamin A Vitamin E	NA	Nicklas et al., 2008
USA *n* D 3939 12 – 18 years Race: White, Black, Hispanic, Other NHANES 1999 – 2002	Cross-sectional	Not specified	(1) 24-h dietary recall Oz./d categorized as 0 oz./d, <6 oz./d, 6 – 12 oz./d, or >12 oz./d	***P*** < 0.05 Fiber Magnesium Potassium Vitamin C NS Calcium Phosphorus Vitamin A Vitamin E	NS Vitamin A	O' Neil et al., (2010
USA *n* D 7250 (% F NR) 2 – 18 years Race: White, Black, Hispanic, Asian NHANES 2003 – 2006	Cross-sectional	Orange	(2) 24-h dietary recalls Oz./d categorized as 0 oz./d or >0 oz./d	***P*** < 0.05 Dietary fiber Magnesium Potassium Vitamin C NS Vitamin A	***P***<0.05 Vitamin A Vitamin C	O' Neil et al., (2011a
USA %F: NR	Cross-sectional	Not specified	Oz./d (2) 24-h dietary recalls	Dietary Fiber 2 – 5 y ***P*** D 0.06	NA	O' Neil et al., 2011b

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Table 2 Studies on dietary nutrient intake and adequacy of shortfall nutrients and 100% fruit juice consumption among children ***(Continued)***

Study population	Study design	Type of 100% fruit juice	Measurement of consumption	Intake	Adequacy	Reference
2 – 5 years (n D 1665) 6 – 12 years (n D 2446) 13 – 18 years (n D 3139) Race: NR NHANES 2003 – 2006				6 – 12 y ***P*** < 0.0001 13 – 18 y ***P*** < 0.0001		
USA *n* D 7250 (49% F) 2 – 18 years Race: NR NHANES 2003 – 2006	Cross-sectional	Not specified	Oz./d categorized as 0 oz./d, <6 oz/d, 6 – 12 oz./d, or >12 oz./d	***P*** < 0.05 Vitamin A Vitamin C Phosphorus Magnesium Potassium NS Dietary fiber Vitamin E	***P*** < 0.05 Vitamin A Vitamin C Phosphorus Magnesium	O’ Neil et al., (2012

F, female; NA, not accessed; NS, not significant; NR, not reported; g, grams.

juice was associated with lower PI. Taken collectively, results of all four studies suggest the lack of a clear association between consumption of 100% fruit juice and PI in children.

BMI z-scores

In children, BMI varies with age and gender due to individual growth rates and changes in body composition during developmental stages; since BMI z-scores account for these factors, this measure is often used to assess weight status in children. Five studies examined the relationship between 100% fruit juice and BMI z-scores (Field et al., 2003; Libuda et al., 2008; Nicklas et al., 2008; O’ Neil et al., 2010; Taber et al., 2012). Among these, two studies used data from the National Health and Nutrition Examination Survey (NHANES), a nationally representative population, and neither showed an association between consumption of 100% fruit juice and BMI z-scores (Nicklas et al., 2008; O’ Neil et al., 2010). Three longitudinal studies examined changes in BMI z-scores over time (Field et al., 2003; Libuda et al., 2008; Taber et al., 2012). Field et al. (2003) reported on children aged nine to 14 years (*n* D 16,886; 68% female) using intake data from at least two food frequency questionnaires. Results of that study suggested a sig- nifi (*P* D 0.003) relationship between consumption of 100% fruit juice and subsequent changes in BMI z-score for females when the model was adjusted for total energy intake; however, the effect size was very small (**b** D 0.003). There was no association between 100% fruit juice intake and changes in BMI z-score in males. In a smaller study of children (*n* D 244, aged nine to 18 years; 49% female) by Libuda et al. (2008), only females showed a signifi t increase (*P* D 0.013) in BMI z-scores with increased con- sumption of 100% fruit juice over a five-year period (**b** D 0.096). According to Taber et al. (2012), in a time series design of the Youth Risk Behavior Study (*n* D 272,044; 49% female) that combined cross-sectional samples from the 2001, 2003, 2005, and 2007 surveys of children aged 14 to 18 years, consumption of 100% fruit juice was inversely associated with BMI z-score (*P* < 0.05) among females only. Self-reported height and weight and use of food frequency questionnaires were notable limitations of this study. Confl results in a small number of studies make it diffi t to determine the overall relationship between consumption of 100% fruit juice and BMI z-scores.

Fat Mass

Five studies examined the relationship between consumption of 100% fruit juice in children and different measures of fat mass, including waist circumference, triceps or subscapular skin folds, or percentage of body fat (Libuda et al., 2008; Nicklas et al., 2008; Fiorito et al., 2009; O’ Neil et al., 2010; Wang et al., 2012). Among these, three cross-sectional studies used the NHANES data to examine skin folds or waist circumference and found no association with consumption of 100% fruit juice (Nicklas et al., 2008; O’ Neil et al., 2010; Wang et al., 2012). The two longitudinal studies showed that consumption of 100% fruit juice was not associated with changes in triceps and subscapular skinfolds, waist circumference, or percentage of body fat as determined by dual-energy X-ray absorptiometry (Libuda et al., 2008; Fiorito et al., 2009). In summary, the evidence reviewed does not support any association between 100% fruit juice consumption and weight status or adiposity (e.g. BMI percentile, weight gain, BMI z-score, and fat mass) in children aged two to 18 years. In summary, the overall strength of the reviewed evidence regarding 100% fruit juice consumption and weight status or adiposity was scored as a grade II (fair), as the currently available evidence lacks a clear association.

ASSOCIATION BETWEEN CONSUMPTION OF 100% FRUIT JUICE AND THE DIETARY INTAKE AND NUTRIENT ADEQUACY OF SELECT SHORTFALL NUTRIENTS

Research Reviewed

Selection of nutrients investigated in this review was based on the identification of the following as shortfall nutrients by the Dietary Guidelines for Americans (United States Department of Agriculture and United States Department of Health and Human Services, 2010): dietary fiber, vitamins A, C, and D, calcium; potassium, and magnesium. In addition, the relationship between consumption of 100% fruit juice and nutrient intake/adequacy of vitamin E and iron were evaluated. To investigate the relationship between consumption of 100% fruit juice and nutrients, assessment of nutrient intake or nutri- ent adequacy was used. These two assessment measures of die- tary intake differ in that the former does not compare intake with dietary recommendations. To determine nutrient ade- quacy, usual intake must be available. For population-based studies, nutrient adequacy is based on the percentage of indi- viduals meeting the estimated average requirement (EAR) (United States Department of Agriculture National Agricul- tural Library, 2015). For the nutrients that do not have an established EAR (e.g. dietary fiber and potassium), nutrient adequacy is based on the percentage of individuals above the adequate intake (AI) levels for those nutrients.

Ten cross-sectional studies evaluating the association of 100% fruit juice consumption and nutrient intake or nutrient adequacy of the selected shortfall nutrients met the inclusion criteria (Dennison et al., 1998; Stroehla et al., 2005; Forshee et al., 2006; LaRowe et al., 2007; Nicklas et al., 2008; O' Neil et al., 2010, 2011a, 2011b, 2012; Fulgoni et al., 2012); however, only eight studies were used in data analysis. The other two studies were excluded from evidence analysis as they either looked at a comparison of averages among years (Fulgoni et al., 2012) or the contribution of food sources to micronutrient intake (as a percentage of each micronutrient and dietary fiber) and did not include specifi data on dietary intake or nutrient adequacy of 100% fruit juice (Stroehla et al., 2005).

Vitamin A

Vitamin A intake was assessed in six cross-sectional studies (Dennison et al., 1998; LaRowe et al., 2007; Nicklas et al., 2008; O' Neil et al., 2010, 2011a, 2012). Three of these six studies also reported on adequacy of vitamin A intake (O' Neil et al., 2010, 2011a, 2012). LaRowe et al. (2007) reported that children in a 100% fruit juice cluster consumed more ($P <$ 0.05) retinol activity equivalents (RAE) of vitamin A (68-mg) compared with children in a mix-lite beverage (all beverages except milk, water, and 100% fruit juice) cluster. Similarly, in another study, 100% fruit juice consumers were also reported to consume more (P D 0.05) RAE of vitamin A (47.4-mg) than non-consumers (O' Neil et al., 2012). The three studies that reported on nutrient adequacy demonstrated that consumption of 100% fruit juice was associated with greater ($P < 0.05$) adequacy of vitamin A intake when compared with non-consumers (O' Neil et al., 2010, 2011a, 2012). In these studies, consumers of 100% fruit juice were 10 to 18% less likely to fall below the EAR for vitamin A than non-consumers. One limiting factor in interpreting these outcomes is that retinol or beta-carotene intake was not reported relative to 100% fruit juice consumption; however, the studies that used the RAE for vitamin A accounted for different bioactivities of retinol and pro-vitamin A carotenoids. The overall strength of the available evidence was scored as grade III (limited). Thus, there is limited evidence that children who consume 100% fruit juice may have higher intake and adequacy of vitamin A.

Vitamin C

Six studies met the inclusion criteria for evaluating vitamin C intake and consumption of 100% fruit juice (Dennison et al., 1998; LaRowe et al., 2007; Nicklas et al., 2008; O' Neil et al., 2010, 2011a, 2012). Two of these studies also reported on adequacy of vitamin C intake (O' Neil et al., 2011a, 2012). On the basis of intake, all six studies reported that consumption of 100% fruit juice was associated with higher ($P < 0.05$) vitamin C intake compared with non-consumers. More specifi Nicklas et al. (2008) and O' Neil et al. (2010) compared different levels of 100% fruit juice consumption (0 to >12 fl oz./day) with non-consumers and observed a signifi antly higher ($P < 0.05$) vitamin C intake with each level of 100% fruit juice consumption. In both of these studies, intake of vitamin C varied directly with the amount of juice consumed such that children consuming higher quantities of 100% fruit juice (> 12 fl oz./d) had intake levels of 120 – 179-mg vitamin C higher than non-consumers. Children consuming 6 – 12 fl. oz./d of 100% fruit juice had intake levels of 60 – 75-mg vitamin C higher than non-consumers. In the two studies that assessed vitamin C adequacy, consumers of 100% fruit juice were more (P :S 0.05) likely to meet the EAR for vitamin C than non-consumers (O' Neil et al., 2011a, 2012). Although approximately 30 – 40% of non-consumers fell below the EAR for vitamin C, only <0.1% of the 100% fruit juice consumers fell below the EAR for vitamin C. The overall strength of the available evidence was scored as grade I (good). Evidence suggests that children who consume 100% fruit juice have higher levels of vitamin C intake and lower levels of vitamin C inadequacy.

Vitamin D

One hundred percent fruit juice can be fortified with vitamin D, yet no articles evaluating vitamin D intake or adequacy and a potential association with 100% fruit juice consumption were identified. The lack of research evaluating this association may be due, in part, to the fact that the special database for vitamin D only became available in 2005. A grade V (not assignable) was scored, indicating that no evidence was found.

Vitamin E

Three studies assessed the relationship between 100% fruit juice consumption and vitamin E intake (Nicklas et al., 2008; O' Neil et al., 2010, 2012). In addition, one of these also reported on adequacy of vitamin E intake (O' Neil et al., 2012). None of the studies reported a signifi t association between 100% fruit juice consumption and vitamin E intake or adequacy. However, it must be acknowledged that 100% fruit juice is not a good source of vitamin E. The overall strength of the available evidence was scored as grade II (fair). In conclusion, consumption of 100% fruit juice is not associated with the intake or adequacy of vitamin E in children.

Calcium

Five studies were identified that assessed calcium intake and its relationship with 100% fruit juice consumption (Dennison et al., 1998; Forshee et al., 2006; LaRowe et al., 2007; Nicklas et al., 2008; O' Neil et al., 2010). Forshee et al. (2006) observed that in males and females aged 6 – 11 years, calcium intake was higher ($P < 0.05$) in those consuming 100% fruit juice; however, among children aged 12 – 19 years, calcium intake was only higher (P D 0.05) among males consuming 100% fruit juice. LaRowe et al. (2007) reported that consumers of 100% fruit juice had a higher ($P < 0.05$) intake of calcium by 125 mg compared with subjects who consumed a mix-lite beverage. Others have observed no effect on calcium intake on consumers of 100% fruit juice compared with non-consumers (Nicklas et al., 2008; O' Neil et al., 2010; Dennison et al., 1998). The overall strength of the available evidence was scored as grade III (limited). Based on the limited and somewhat conflicting evidence, consumption of 100% fruit juice may not be associated with higher intake of calcium.

Iron

Three studies were identifi which reported iron intake while no study was identifi which reported the adequacy of iron intake (LaRowe et al., 2007; Nicklas et al., 2008; O' Neil et al., 2010). All three studies observed higher ($P < 0.05$) iron intake (mg) with higher levels of 100% fruit juice consumption. LaRowe et al. (2007) observed that consumers of 100% fruit juice had higher ($P < 0.05$) iron intake than children who consumed a mix-lite beverage or milk. Two studies using the NHANES data showed that significantly higher iron intake ($P < 0.05$) only occurred with consumption of 100% fruit juice in amounts greater than 6 fl. oz./d (Nicklas et al., 2008; O' Neil et al., 2010). These results suggest that there was an association between consumption of 100% fruit juice and iron intake. The overall strength of the available evidence was scored as grade III (limited). Children who consume 100% fruit juice may have marginally higher levels of iron intake compared with children not consuming 100% fruit juice. However, since 100% fruit juice is not a good source of dietary iron, the association reported may be related to an overall healthy diet.

Magnesium

Two studies reported on the association between magnesium intake and 100% fruit juice consumption (Nicklas et al., 2008; O' Neil et al., 2010) and two studies reported on adequacy of magnesium intake associated with consumption of 100% fruit juice (O' Neil et al., 2011a, 2012). All four studies reported that consumers of 100% fruit juice had higher ($P < 0.05$) magnesium intake than non-consumers. Children who consumed more than 12 fl oz./d had an average intake of magnesium of 28.5 to 50 mg higher ($P < 0.05$) than non-consumers, while children who consumed 6 to 12 fl. oz./d of 100% fruit juice had an average intake of 18 – 28-mg more ($P < 0.05$) magnesium than non-consumers (Nicklas et al., 2008; O' Neil et al., 2010). With regard to adequacy of magnesium intake, O' Neil et al. (2011a, 2012) reported that 100% fruit juice consumers were 13 – 20% more ($P < 0.05$) likely to meet the EAR for magnesium intake than non-consumers. The overall strength of the available evidence was scored as grade III (limited). Children who consumed 100% fruit juice may have higher magnesium intake and adequacy of this nutrient.

Potassium

Five studies met the inclusion criteria for assessing the relationship between potassium intake or adequacy and 100% fruit juice consumption (Dennison et al., 1998; Nicklas et al., 2008; O' Neil et al., 2010, 2011a, 2012). Potassium intake was reported in all studies while only one study reported on adequacy of potassium intake (O' Neil et al., 2012). All five studies reported that consumers of 100% fruit juice had significantly higher ($P < 0.05$) potassium intake than non-consumers. Children who consumed more than 12 fl. oz./d had an average intake of 770 – 1,056-mg potassium higher ($P < 0.05$) than non-consumers, while children who consumed 6 to 12 fl. oz./d of 100% fruit juice consumed 405 – 468-mg more ($P < 0.05$) potassium than non-consumers (Nicklas et al., 2008; O' Neil et al., 2010). With regard to adequacy of intake, consumption of 100% fruit juice was associated with greater (P D

0.05) adequacy of potassium intake (1.9% higher in consumers) (O' Neil et al., 2012). The overall strength of the available evidence was scored as grade II (fair). Children who consumed 100% fruit juice had higher levels of potassium intake and adequacy. This was not surprising since many of the frequently consumed juices are rich sources of potassium.

Dietary Fiber

Five identifi studies reported on an association between intake of dietary fiber and consumption of 100% fruit juice (LaRowe et al., 2007; O' Neil et al., 2010, 2011a, 2011b, 2012). One of the studies also reported on the adequacy of dietary fi intake (O' Neil et al., 2012). Three of the five studies reported that consumers of 100% fruit juice had higher ($P < 0.05$) dietary fi er intake than non-consumers (O' Neil et al., 2010, 2011a, 2011b). In addition, O' Neil et al. (2010) reported that children who drank at least 6 fl oz./d of 100% fruit juice had 1 – 2 g higher intake of dietary fiber than children who did not consume 100% fruit juice. In terms of adequacy of dietary fi er intake and 100% fruit juice consumption, no association was shown (O' Neil et al., 2012). The overall strength of the available evidence was scored as grade III (limited). It should be acknowledged that 100% fruit juice is not a good source of dietary fiber. Nevertheless, children who consume 100% fruit juice may have higher levels of dietary fiber intake in part since consumption of 100% fruit juice has been associated with greater intake of whole fruit.

ASSUMPTIONS AND LIMITATIONS

Since study designs and methodologies for evaluating 100% fruit juice intake and outcomes varied greatly, several assumptions and limitations were associated with this review, and hence with the conclusions that were drawn. First, different dietary assessment and clinical measures were used in these studies. In turn, each method used had inherent limitations. For example, one limitation of dietary records and recalls is the ability of responders to report accurate intake and estimate portion sizes. This is especially true for the proxies that report intake of young children; the proxies (usually parents) may know what their child ate at home but may not know what the child ate outside the home. With 100% fruit juice, another limitation is the possibility that self-reported data may include juice drinks or juice cocktails that are not by definition "100% fruit juice." In addition, among the studies evaluated, varying amounts of juice were consumed with results analyzed collectively. Therefore, evidence summaries are based on the relationship between a range of 100% fruit juice intake levels and specific outcomes. Lastly, evidence from cross-sectional studies does not allow for causal determi- nation of individual outcomes being solely attributed to con- sumption of 100% fruit juice.

CLINICAL APPLICATIONS AND CONCLUSIONS

Overall, the evidence did not support an association between 100% fruit juice consumption and weight status or adiposity in children after controlling for total energy intake and other covariates. Although a signifi associa- tion was not observed, it should be emphasized that practi- tioners need to assess weight status and dietary intake on a case-by-case basis to monitor these associations at an indi- vidual level, given the fact that over-consumption of any food may lead to weight gain. It can also be concluded that consumption of 100% fruit juice has a varied impact on the intake and adequacy of shortfall nutrients. On the basis of the data, consumption of 100% fruit juice poten- tially contributed to the intake and adequacy of dietary fi vitamin C, magnesium, and potassium among chil- dren. Differences in methodology and study design were present among the studies reviewed, thus causal determina- tion and identifi of 100% fruit juice as the sole impact factor infl cing weight status or the intake and adequacy of shortfall nutrients among children may not be concluded.

In summary, consumption of 100% fruit juice within the context of an overall healthy dietary pattern may play a role in preventing nutrient deficiency without contributing to excess weight gain. Nevertheless, 100% fruit juice should not replace all whole fruit in the diet and these findings do not negate the effects of whole fruit consumption in promoting the same outcomes.

CONFLICT OF INTEREST

The following authors reported potential conflicts of interest pertaining to this review:

- Carol O' Neil participates in a working group that has received current and past funding from Juice Products Association.
- Paula Ziegler and Taylor Wolfram based on employment at the Academy of Nutrition and Dietetics.

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