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Commentary

100 % Fruit juice: perspectives amid the sugar debate

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A number of clinical and epidemiological studies have reported positive associations between high sugar or fructose intake and the risk for several chronic diseases or other conditions, including overweight and obesity, diabetes, insulin resistance, metabolic syndrome and hyperlipidaemia[1,2]. However, there are also studies that fail to support this relationship, especially when intakes are at levels that mirror typical consumption[3]. The research on fructose also has implicated this sugar as having possible health risks, although the interpretation of this hypothesis has noteworthy limitations. The results of animal studies are frequently extrapolated to man even though there are metabolic differences related to fructose metabolism, while human clinical studies often suffer from methodological issues that can affect their interpretation and application to the general human population[4,5]. For example, in most clinical studies fructose levels far exceed those consumed by the general population. Nevertheless, the potential health effects related to the consumption or overconsumption of sugars and fructose have captured the spotlight in scientific journal editorials and commentary[6,7] and the lay press[8–10], as well as in business/finance institution reports related to global sugar consumption and health impacts[11]. While most of the attention has focused on beverages containing added sugars, particularly high-fructose corn syrup, 100 % fruit juices (FJ) have been swept into the discourse because of their sugar and fructose contents[12,13], which come not from added sugars but as naturally occurring sugars in the whole fruit. As a result, 100 % FJ is often discussed in a context that focuses solely on its sugar content and neglects the nutritional value and potential health benefits associated with including 100 % FJ in the diet. Moreover, the evidence to date suggests that the adverse effects associated with excess added sugar or fructose intake are not observed with respect to the consumption of 100 % FJ at typical amounts.

Research on 100 % fruit juice

A number of observational studies have investigated the relationship between 100 % FJ intake and anthropometric measures in children and/or adolescents. A comprehensive review article published in 2008 evaluated the results of twenty-one studies (nine cross-sectional and twelve longitudinal)[14]. Only three out of nine cross-sectional studies and three out of twelve longitudinal studies reported a positive association between 100 % FJ intake and weight status. After critically reviewing the quality of the studies, the authors concluded that there was no systematic association between 100 % FJ intake and body weight in children or adolescents. As analysed in the review, three longitudinal studies reported significant associations between 100 % FJ intake and weight or BMI in adolescent girls in Germany[15] or low-income children who were overweight or at risk for overweight at baseline in the USA[16,17]. The two latter studies included relatively large sample sizes, yet none of the three studies used a nationally representative sample. Observational studies concerning FJ intake and anthropometric measures in children and adolescents published since the 2008 review are summarized in Table 1. Several cross-sectional and longitudinal studies published since the 2008 review report no association between 100 % FJ consumption and obesity or BMI in children and adolescents, including Mexican-American children in California[18], Swedish adolescents[19], Greek schoolchildren[20], Canadian children[21], children in a California WIC (Special Supplemental Nutrition Program for Women, Infants, and Children)[22], and adolescents in Project EAT (Eating Among Teens)[23] and the National Health and Nutrition Examination Survey (NHANES)[24]. A multi-year and multi-state analysis of over 272 000 adolescents from the Youth Risk Behavior Survey reported an inverse association between 100 % FJ intake and BMI in girls and a null association in boys[25]. These results should be interpreted with caution since height and weight were self-reported and adolescent females tend to under-report their weight[26,27]. One longitudinal study reported a significant association between the amount of FJ consumed by children at age 1 year and BMI *Z*-score during early and mid-childhood[28], while an inverse association was reported between fruit and vegetable juice intake during childhood and waist circumference and skinfold measurements in adolescence[29]. Two recent reviews of the literature, including an analysis by a workgroup on behalf of the Academy of Nutrition and Dietetics' Evidence Analysis Library, concluded that the majority of evidence does not support an association between 100 % FJ consumption and weight status or adiposity in children 2–18 years of age[30,31]. Readers desiring more detailed information about individual studies should consult these reviews.

For adults, no association between 100 % FJ consumption and waist circumference was observed in the Coronary Artery Risk Development in Young Adults (CARDIA) longitudinal cohort[32], while inverse associations between 100 % FJ and BMI have been reported in

Table 1 Observational studies published since 2008 evaluating fruit juice intake and anthropometric measures in children and adolescents

Reference	Study/subject description	Dietary and anthropometric information collected	Anthropometric outcome measures	Covariates	Results
Cross-sectional studies					
Nicklas *et al.*[60]	NHANES 1999–2002 3618 children aged 2–11 years, 51 % male, 29 % white, 29 % black, 33 % Hispanic	Multiple-pass 24 h recall assessing 100 % juice intake categorized by non-consumers and 3 groups of 100 % juice consumers (>0 to ≤6 fl oz/d; >6 to ≤12 fl oz/d; >12 fl oz/d) Ht, Wt, WC and skinfolds measured	Wt, BMI, WC, triceps skinfold, weight-for-age percentile, weight-for-age *Z* score, BMI-for-age percentile, BMI-for-age *Z* score; based on CDC growth chart programs Likelihood of overweight or at risk of overweight Juice intake by weight category	Sex, ethnicity, age, energy intake	NS for juice intake and any outcome measure
Vagstrand *et al.*[19]	Stockholm Weight Development Study (SWEDES) 474 children aged 15–17 years, 42 % male	Dietary questionnaire assessing FJ intake during the past 3 months using a semi-quantitative approach with predefined portion sizes Ht and Wt measured	BMI	None; a residual method was used to make the food group variables independent of total energy intake	No significant correlation between FJ consumption and BMI
O'Neil *et al.*[24]	NHANES 1999–2002 3939 children aged 12–18 years, 51 % male, 25 % non-Hispanic white, 29 % non-Hispanic black, 42 % Hispanic	Multiple-pass 24 h recall assessing 100 % juice intake categorized by non-consumers and 3 groups of 100 % juice consumers (>0 to ≤6 fl oz/d; >6 to ≤12 fl oz/d; >12 fl oz/d) Ht, Wt, WC and skinfolds measured	Wt, BMI, WC, triceps skinfold, weight-for-age percentile, weight-for-age *Z* score, BMI-for-age percentile, BMI-for-age *Z* score; based on CDC growth chart programs Likelihood of overweight or at risk of overweight Juice intake by weight category	Sex, ethnicity, age, energy intake	NS for juice intake and any outcome measure
Danyliw *et al.*[21]	Canadian Community Health Survey 2·2 10 038 children aged 2–18 years, included white and non-white children (percentages not reported)	Automated multiple-pass 24 h recall assessing FJ intake by volume, container type, or standard images of various sizes of glasses and mugs Beverage intake clustered by dominant beverage consumed Ht and Wt measured	OR for overweight/obesity (defined as BMI ≥ 85th percentile)	Age, sex (2- to 5-year-olds only), energy, ethnicity, sedentary activity and significant sociodemographic characteristics	NS for FJ intake and odds for being overweight/ obese in children aged 2–11 years (association not analysed in older age groups)

Table 1 *Continued*

Reference	Study/subject description	Dietary and anthropometric information collected	Anthropometric outcome measures	Covariates	Results
Beck *et al.*[18]	Participants in the Kaiser Permanente Health Plan of Northern California (San Francisco Bay area) 319 Mexican-American children aged 8–10 years, 47 % male	Adapted from the Youth/ Adolescent FFQ Assessed 100 % FJ intake based on the number of days per week consumed and typical volume consumed, then converted to number of 8 fl oz servings per week Ht and Wt measured	OR for obesity (defined as BMI ≥ 95th percentile)	Model-dependent covariates were maternal BMI, country of origin, Spanish language use, education, household income, occupational status; child age, sex, fast-food consumption, screen time, PA	NS for 100 % FJ intake and odds for being obese
Papandreou *et al.*[20]	School-based sample from Thessaloniki, Greece 607 children aged 7–15 years, 53 % male	Three 24 h recalls (2 weekdays, 1 weekend) assessing 100 % FJ intake categorized as none, > 0 to 180 ml, >180 to 360 ml, and >360 ml Ht and Wt measured	Overweight and obese status as defined by IOTF criteria	None for 100 % FJ analysis and results	NS association between 100 % FJ and overweight or obesity
Davis *et al.*[22]	Los Angeles County WIC program 2295 children aged 2–4 years, 53 % male, 84 % Hispanic, 3 % non-Hispanic white, 5 % African-American	Telephone-administered survey 100 % juice intake assessment and amounts unclear Ht and Wt measured and obtained from WIC administrative data	OR and prevalence of overweight (BMI-for-age ≥85th percentile) and obesity (BMI-for-age ≥95th percentile)	Sex, ethnicity, age, mother's gestational diabetes status, birth weight	NS for 100 % FJ intake and odds for being overweight or obese 100 % FJ not linked to obesity prevalence
Longitudinal studies					
Vanselow *et al.*[23]	Project EAT-I and II from Minneapolis/St. Paul area 2294 middle- and high-school students, mean age 14·9 years at study entry, 45 % male, 64 % white, 18 % Asian-American, 10 % African-American, 4 % Hispanic	Youth and adolescent FFQ assessing orange and apple juice intake categorized by frequency of consumption as rarely/ never, 0·5–6 times/week and ≥ 7 times/week for the analysis Ht and Wt self-reported	Change in BMI over 5 years	Age, sex, race/ethnicity, SES, baseline BMI, baseline of same beverage Additionally, in a separate model for cohort, baseline and T2 strenuous PA, T2 weekday TV watching and coffee and tea consumption	NS for orange or apple juice intake and change in BMI over 5 years
Fiorito *et al.*[76]	Young girls living in Central Pennsylvania 166 girls aged 5 years at baseline, predominantly non-Hispanic and white, assessed every 2 years for 10 years	Three 24 h recalls each year assessing 100 % FJ consumption, expressed as number of 8 fl oz servings Ht, Wt, skinfold and WC measured	%BF, WC, BMI-for-age percentile	24 h energy at age 5, parental education, family income, maternal BMI at baseline, beverage intake measured at the same time point as adiposity	NS for 100 % FJ intake and adiposity

Table 1 *Continued*

Reference	Study/subject description	Dietary and anthropometric information collected	Anthropometric outcome measures	Covariates	Results
Taber *et al.*[25]	State-level Youth Risk Behavior Surveys on four years between 2001 and 2007 53 292 to 82 296 (depending on year) 9th–12th grade students from 29 states, 51 % male, 61–67 % non-Hispanic white, 14–15 % non-Hispanic black, 11–16 % Hispanic	Written questionnaire assessing 100 % FJ intake in servings/d Ht and Wt self-reported	BMI percentile	Race/ethnicity, age; plus state-specific poverty status, income inequality, violent crime rate and cigarette taxes	Greater juice consumption associated (cross-sectionally) with lower mean BMI percentile among girls (no association in boys)
Hasnain *et al.*[29]	Framingham Children's Study 98 non-Hispanic children aged 3–5 years at baseline, all non-Hispanic white, followed for 12 years	Multiple sets of 3 d dietary records annually assessing intakes of fruit and vegetable juices including sweetened and unsweetened juice (but not part-FJ) Mean intake of FJ from all dietary records measured as fl oz/d and categorized into tertiles Ht, Wt, WC and skinfolds measured	BMI, four skinfold site measurements, WC, %BF	Age, baseline anthropometry, %E from fat, mean TV and video time, other beverage intake, mother's education, mother's BMI	Highest tertile of fruit and vegetable juice intake during childhood associated with significantly smaller WC ($P=0{\cdot}0328$) and sum of all skinfolds ($P=0{\cdot}0383$) at age 15–17 years compared to lowest tertile NS for fruit and vegetable juice intake and BMI or %BF
Sonneville *et al.*[28]	Project Viva prospective cohort (Massachusetts) 1163 children aged 1 year at study entry with follow-up at early (median age 3·1 years) and mid (median age 7·7 years) childhood, 50 % male, 70 % white, 12 % black, 4 % Hispanic	100 % FJ intake at age 1 year (fl oz/d) and at follow-up using an FFQ (converted to servings/d) Ht and Wt measured	BMI *Z*-score	Maternal age, education, pre-pregnancy BMI, income; child age, sex, race/ethnicity, weight-for-length *Z*-score at age 1 year, juice and water intake at age 1 year Adjusted for energy intake in additional modelling	FJ intake at age 1 year associated with significantly higher BMI *Z*-score at early ($P=0{\cdot}04$) and mid-childhood ($P=0{\cdot}01$) in univariate and adjusted models Additional adjustment for energy intake attenuated the association in early childhood

NHANES, National Health and Nutrition Examination Survey; WIC, Special Supplemental Nutrition Program for Women, Infants, and Children; EAT, Eating Among Teens; fl oz, fluid ounces (1 fl oz = 29·57 ml); Ht, height; Wt, weight; WC, waist circumference; FJ, fruit juice; CDC, Centers for Disease Control and Prevention; IOTF, International Obesity Task Force; %BF, percentage body fat; PA, physical activity; SES, socio-economic status; T2, time 2; TV, television; %E, percentage of energy intake.

other studies[33,34]. However, a large study using the Nurses' Health Study I and II, and Health Professionals Follow-Up Study cohorts reported a significant and positive association between the increase in FJ intake and weight gain of about 0·15 kg (0·3 lb) in adults over each 4-year follow-up study period[35]. Demographic, sample size or other differences between cohorts may account for the differences in results. Overall, the results of observational studies in children and adults on 100 % FJ intake and body weight are mixed with the majority of studies reporting no association. Randomized clinical trials are lacking and needed to determine the existence of a causal relationship.

Study results are also mixed for associations between 100 % FJ intake and risk for type 2 diabetes, with the majority of studies reporting no significant effects. 100 % FJ intake was positively associated with risk of type 2 diabetes in several studies, including middle-aged women in the Nurses' Health Study[36], middle-aged Chinese men and women living in Singapore[37], and in an analysis of three large US health professional cohorts (including the Nurses' Health Study as previously analysed and reported in Bazzano *et al.*)[38]. However, a systematic review and meta-analysis evaluating four prospective cohort studies representing over 137 000 participants concluded that the intake of 100 % FJ was not significantly associated with the risk for type 2 diabetes[39]. FJ intake was not associated with risk for incident type 2 diabetes in studies in African-American women[40], Japanese-Brazilians[41], Japanese[42], middle-aged women in the Nurses' Health Study II cohort[43], French women[44] and healthy men in the Health Professionals Follow-Up Study cohort[45]. No association between pre-pregnancy FJ intake and risk for gestational diabetes was reported for women in the Nurses' Health Study II[46]. An analysis of the European Prospective Investigation into Cancer and Nutrition (EPIC) cohort reported no association between the consumption of juices and nectars and the incidence of type 2 diabetes in over 11 000 subjects[47]. In this analysis, the juice group also included vegetable juices as well as nectars that may have contained up to 20 % added sugars, so results should be interpreted with some caution. European men and women without diabetes consumed higher amounts of juice compared with those with diabetes[48].

Metabolic syndrome is a cluster of risk factors that increase the risk for CVD and diabetes[49]. Studies using the cross-sectional NHANES[34] and longitudinal CARDIA[32] data sets report no association between 100 % FJ intake and risk for metabolic syndrome. A study of over 1100 adults from the Bogalusa Heart Study reported that 100 % FJ intake was higher in those with no risk factors for metabolic syndrome *v.* those having one or two risk factors[50]. Substituting sugar-sweetened beverages with moderate amounts of homemade FJ was associated with a 30 % decreased risk for metabolic syndrome among Costa Rican adults[51]. An analysis of NHANES 2003–2006 data reported a 36 % reduced odds or likelihood for metabolic syndrome in men who consumed orange juice compared with men who did not consume orange juice, with a null association in women[52]. FJ intake has been associated with an increased risk for impaired glucose tolerance in a Japanese-Brazilian population[41], but has been inversely related to fasting glucose in the Framingham Offspring cohort[53].

Intake of 100 % FJ does not appear to have adverse effects on blood lipids and may be beneficial in some cases. FJ consumption was not associated with significant effects on total cholesterol, LDL-cholesterol or HDL-cholesterol in a meta-analysis of nineteen randomized controlled studies[54]. A study using the CARDIA cohort reported no association between FJ intake and the CVD risk factors elevated TAG, elevated LDL-cholesterol or low HDL-cholesterol in adults[32]. Substituting sugar-sweetened beverages with moderate amounts of homemade FJ was associated with increases in HDL-cholesterol[51]. Clinical studies have reported beneficial effects on blood lipids of some individual juices including orange juice and LDL-cholesterol[55,56] and grapefruit juice and HDL-cholesterol[57].

Nutritional and other benefits

100 % FJ are nutrient-dense beverages that provide a variety of vitamins and minerals in varying amounts depending on the juice type, including vitamin C, potassium, thiamin, vitamin B_6, folate and vitamin A, as well as calcium and vitamin D in some fortified juices. 100 % FJ are also sources of flavonoids, including polyphenolic compounds that may confer health benefits[58,59] and are readily found in a variety of 100 % FJ. Consumption of 100 % FJ has been positively associated with the intake of key nutrients, such as vitamin C, folate, potassium and magnesium[24,60,61], which have been identified as underconsumed nutrients or nutrients of concern (potassium) in the 2010 Dietary Guidelines for Americans[62]. Intake of 100 % FJ also has been associated with enhanced diet quality based on Healthy Eating Index scores[63]. Approximately 60 % of children 4–8 years of age and at least 80 % of older children and adults do not meet fruit intake recommendations[64]. While whole fruit should be chosen first, 100 % FJ can complement whole fruit and, when consumed in appropriate amounts, is a practical strategy to help Americans meet daily fruit intake recommendations. In fact, 100 % FJ consumers have been reported to have higher intakes of whole fruit than non-consumers[24,38,60], suggesting that 100 % FJ is complementary to, and not a replacement for, whole fruit in the diet.

From strictly an economic standpoint, 100 % FJ can have advantages over whole fresh fruit. Based on data from the US Department of Agriculture's Agricultural Marketing Service[65], the average price for a non-organic navel orange for the time period 19 September 2014 to 26 December 2014 was $US 0·81. Based on Nielsen Scantrack data, the season-to-date (28 September 2014 to 17 January 2015) price for reconstituted orange juice was $US 4·99/gallon[66], or approximately \$US 0·31 for 8 fl oz (237 ml), making an 8 fl oz (237 ml) serving of 100 % orange juice just over one-third the cost of a fresh orange in a practical serving-to-serving comparison. These cost differences could be consequential for lower-income individuals, many of whom have lower intake levels of fruit[67], poorer diet quality[68] and may be at increased risk for chronic disease[69], as well as institutions such as day-care centres, child or adult feeding programmes and schools that purchase and serve food and beverage items in large quantity. The longer shelf-life of 100 % FJ compared with most fresh fruits may also help reduce food waste.

As with any caloric food or beverage, it is important that 100 % FJ be consumed in appropriate amounts that do not contribute to excessive energy intake. The American Academy of Pediatrics[70] and the American Heart Association[71] have suggested guidelines and limits for juice intake in children: 4–6 fl oz/d (118–177 ml/d) for children 1–6 years of age and 8–12 fl oz/d (237–355 ml/d) for older children and adolescents. Juice should not be given to infants 6 months of age and younger and should never be given in a bottle. The Robert Wood Johnson Foundation has issued beverage guidelines for children and adults, with recommended 100 % FJ amounts similar to but slightly more restrictive than those of the American Academy of Pediatrics[72]. Some data suggest that sugar-sweetened beverages (not including 100 % FJ) may be displacing milk from the diet[73,74]. This does not appear to be true with 100 % FJ as children and adolescents who consumed 100 % FJ did not consume significantly less milk compared with non-consumers[24,60]. A study examining changes in sweetened beverage, milk and juice consumption in children between the 5th and 8th grades reported that milk and juice were complements to each other, suggesting that 100 % FJ did not displace milk from the diet[75]. Children consuming 100 % FJ may be considered to have healthier diets because they had higher intakes of several vitamins and minerals and lower intakes of total and saturated fat than non-consumers[24,60].

Summary

There is no consistent evidence that 100 % FJ is independently associated with adverse impacts on weight; in fact, many studies report null associations or inverse associations between 100 % FJ intake and body weight measures. However, the lack of randomized controlled clinical trials precludes the existence of a cause-and-effect relationship between 100 % FJ intake and weight or body composition measures. Studies related to 100 % FJ and type 2 diabetes are equivocal and reinforce the need for more research in this area. That 100 % FJ intake does not appear to be associated with key risk factors for diabetes such as insulin resistance or metabolic syndrome raises questions about the nature of the positive association between 100 % FJ intake and diabetes risk reported in some studies. Given the complex aetiology of diabetes, cross-sectional studies cannot account for all aspects of diet and lifestyle that could impact the development of these conditions; and further research is warranted. Studies on 100 % FJ intake are often confounded by the nature of the beverages included in the category defined as 'juice'. For example, studies may combine the intakes of 100 % FJ and juice drinks and beverages that are not 100 % juice, may contain added sugars and have significantly different nutritional profiles compared with 100 % FJ. Self-reported dietary intake data further confound this issue as consumers may not recognize which products are 100 % FJ and which are not, increasing the likelihood that 100 % FJ intake is misreported. Future research should consider and address these issues.

Overall, there appears to be no reported adverse effects of 100 % FJ consumption on health conditions often associated with excess sugar or fructose intake; some studies report benefits. 100 % FJ has been associated with nutritional benefits and with diets that are of higher quality or more nutritionally complete. The amount of 100 % FJ consumed should be balanced with overall energy intake and expenditure. Intake should especially be monitored in children, particularly those who are overweight or obese. Consumption of 100 % FJ can help satisfy several key recommendations in the 2010 Dietary Guidelines for Americans: specifically, a focus on consuming nutrient-dense foods and beverages, increasing fruit intake and achieving nutrient adequacy. Data suggest that the consumption of 100 % FJ in appropriate amounts would be beneficial rather than detrimental to health.

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