Isoflavones in breastfed infants after mothers consume soy[1–3]

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ABSTRACT

Background: The bioavailability of isoflavones in children after soy exposure is uncertain.

Objective: We aimed to compare isoflavone patterns in infants exposed to isoflavone-containing breast milk (BF), in tofu-fed (TF) infants, and in mothers consuming a soy beverage.

Design: Eighteen nursing mothers who were not feeding soy foods to their infants consumed one daily serving of a soy protein beverage for 2–4 d and collected their own milk and urine and infant urine. Plasma was collected from infants if venous blood draws were ordered by pediatricians. Blood and urine were collected from additional children after they consumed tofu. Isoflavones were measured by liquid chromatography–mass spectrometry.

Results: In 7 subjects, isoflavone values increased significantly from baseline after mothers ate soy: in maternal urine ($\bar{x} \pm$ SEM) from 18.4 ± 13.0 to 135.1 ± 26.0 nmol/mg creatinine, in breast milk from 5.1 ± 2.2 to 70.7 ± 19.2 nmol/L, and in infant urine from 29.8 ± 11.6 to 111.6 ± 18.9 nmol/mg creatinine. The mean isoflavone concentration in plasma obtained from 11 BF infants was 19.7 ± 13.2 nmol/L. TF infants had much higher mean isoflavone values (urine, 229 ± 129 nmol/mg creatinine; plasma, 1049 ± 403 nmol/L). Statistically significant correlations were observed between the types of fluids investigated within mothers, between mothers and infants, and within infants. Urinary isoflavone excretion per hour adjusted for dose per body weight was 81% lower for BF infants and 24% higher for TF infants than for their mothers after eating soy.

Conclusions: More isoflavones appear in children than in adults after adjustment for isoflavone intake. Systemic isoflavone exposure in infants can be determined by urinary analysis. *Am J Clin Nutr* 2006;84:406–13.

INTRODUCTION

Soy foods contain high concentrations of the isoflavones genistein, daidzein, and glycitein (≈ 0.01–0.3% as consumed) and account for most dietary isoflavone exposure (1), particularly in soy-consuming populations (1–4). Isoflavones are efficiently absorbed by adults after oral administration (5–10), and urinary or plasma isoflavones are used as reliable biomarkers of soy consumption in adults (11–18). According to numerous animal and human studies, isoflavones are suggested to protect against many chronic diseases, including breast, prostate, and colorectal cancer; osteoporosis; menopausal symptoms; and cardiovascular disorders (19–25). Isolated isoflavones as present in nutritional supplements are mostly ineffective (26, 27), except

for improving endothelial function (28). Some studies find health benefits from soy foods that are low in or devoid of isoflavones (29, 30), whereas others find that isoflavones from soy alone or in combination with other soy components result in health benefits (27, 28, 31–34).

Although well researched in adults (6–8, 35), the bioavailability of isoflavones after soy exposure has been minimally investigated in infants and children (6–8). In one study, mean plasma isoflavone concentrations in seven 4-mo-old boys fed soy-based formula, cow milk–based formula, or human milk were 3.7, 20, and 16 μmol/L, respectively (36). Urinary isoflavone concentrations were reported to be lower in up to 4-mo-old boys than in adults when both were exposed to comparable isoflavone doses (37). Comparisons in isoflavone bioavailability between children or infants and their mothers in dietary intervention studies have so far not been performed. Details about the absorption, metabolism, and excretion of milk components in infants often remain uncertain, including the fate and quantitative pattern of dietary agents, even vitamins (38, 39). Thus far, no information is available about isoflavone concentrations in infants after they consume isoflavone-containing breast milk. We and others previously showed that lactating women secrete isoflavone into breast milk after soy intake (40, 41) and that this happens in a dose-dependent fashion (42).

We report here on isoflavone values in urine (IU) and plasma (IP) of infants who breastfed from soy-consuming mothers (BF) or who consumed tofu (TF) to find out whether isoflavones consumed by breastfed infants as glucuronate and sulfate conjugates appear in these infants differently than when consumed as β-glucosides as present in soy foods. In addition, we compared these findings with the isoflavone patterns in urine and milk of the soy-consuming mothers (MU and MM, respectively).

SUBJECTS AND METHODS

Subjects and study design

Breastfeeding mothers and their infants were recruited from the local children's hospital and through word of mouth. All were

TABLE 1
Composition of the soy protein beverages consumed by mothers[1]

	With aspartame	Without aspartame
Amount per dose (mg)		
Daidzin	7.5	7.2
Glycitin	1.1	1.1
Genistin	10.3	10.2
Daidzin malonate	11.8	11.7
Glycitin malonate	0.8	0.6
Genistin malonate	13.8	14
Daidzin acetate	2.7	2.7
Glycitin acetate	0.3	0.2
Genistin acetate	2.7	2.6
Daidzein	2.3	2.3
Glycitein	0.1	0.1
Genistein	1.6	1.7
Total daidzein	24.3	24
Total glycitein	2.3	2
Total genistein	28.5	28.5
Total isoflavones	55.1	54.5
Percentage of total (%)[2]		
Glucosides	34	34
Malonyl-glucosides	48	48
Acetyl-glucosides	10	10
Aglucons	7	8
Total daidzein	44	44
Total glycitein	4	4
Total genistein	52	52

[1] Composition by HPLC analysis. According to the manufacturer, the beverages contained 25 g soy protein, 0.5–1 g total fat, 0–5 g cholesterol, 150–240 mg Na, 10–200 mg K, 5–6 g carbohydrates, and various vitamins and minerals and delivered 130 kcal; the net weight was 36.5 g.

[2] Differences from 100% are due to rounding.

healthy and not allergic to soy foods. The eligibility criteria included breastfeeding ≥80% of the time, being able to follow the protocol, and not feeding soy-based infant formula at any time. The protocol required that mothers consume one daily serving (36.5 g) of a soy protein beverage (donated by the Solae Company, St Louis, MO) for 2–4 days. Participants were given the choice of an unsweetened soy protein beverage or one with aspartame. According to the manufacturer, both varieties contained 25 g soy protein, 0.5–1 g total fat, 0–5 g cholesterol, 150–240 mg sodium, 10–200 mg potassium, 5–6 g carbohydrates, and various vitamins and minerals and delivered 130 kcal. As shown in **Table 1**, each contained ≈55 mg isoflavones with the typical pattern (daidzein:genistein:glycitein = 1:1:0.1; mainly glucosides and malonyl glucosides) (43). After the soy beverage was consumed on the last day in the early morning, sample collection was performed that afternoon and was completed within 1–2 h. Mothers collected their milk and urine as well as the infant's urine. Infants were breastfed as usual. Baseline milk and urine samples were collected before the intervention. Blood was collected at that time only from those infants whose pediatrician ordered a diagnostic blood lead level test as recommended in some circumstances in the State of Hawaii. No separate blood draws from infants were performed solely for this study. The urine of the infants who donated blood was collected immediately after the blood draw by using a pediatric urine bag.

A total of 18 mothers and their BF infants (9 males, 9 females) aged 2–45 wk participated in this study. All infants consumed breast milk in frequency and volume ad libitum. Some participants repeated collections after several soy interventions, which were ≥2 wk apart.

To compare the effects of isoflavone exposure via breast milk with that via solid foods, we collected blood and urine additionally from 3 infants (aged 9, 10, and 24 mo; 2 females, one male) 2 to 4 h after they consumed on average 44 g tofu (equivalent to 7.4 mg isoflavones) (43). No samples were collected from their mothers, and values from TF infants were included in the IP-IU comparisons.

The protocol of this dietary intervention study was approved by the Institutional Review Board of Kapiolani Medical Center for Women and Children/Honolulu and the University of Hawaii Committee on Human Subjects. All participants signed an informed consent form for themselves and their children before entry into the study.

Blood was collected in lithium-heparin–containing evacuated tubes, and urine was collected from infants in special sex-specific collection bags in 2 sizes depending on age (First-Time; Hollister Inc, Libertyville, IL). Sterile screw-cap containers were used to collect MM and MU. Immediately after collection, blood was transported at 5–8 °C in the dark to the laboratory via courier, followed by immediate processing and final storage of plasma at −20 °C. Urine and milk samples were allowed to be stored in refrigerators until transported to the laboratory on wet ice via courier. These samples were always kept at temperatures <8 °C until final storage at −20 °C, no later than 24 h after collection. These conditions were shown not to degrade any of the measured isoflavones (data not shown).

Specimen analysis

The soy protein beverage contained 55 mg isoflavones, composed of daidzein, genistein, glycitein, and their glycoconjugates as determined by HPLC with photodiode array detection (PDA) (5), as shown in Table 1. Daidzein, genistein, glycitein, equol, dihydrodaidzein, dihydrogenistein, and O-desmethylangolensin were analyzed from urine, plasma, and human milk by HPLC with PDA followed online by electrospray ionization (negative mode) ion trap mass spectrometry (ESI-MS) (44, 45). In brief, triply ^{13}C-labeled internal standards of daidzein, genistein, equol, and O-desmethylangolensin (University of St Andrews, St Andrews, United Kingdom) were added to each specimen hydrolyzed with glucuronidase and sulfatase (Sigma Chemical Co, St Louis, MO, or Roche Applied Sciences, Indianapolis, IN) followed by repeated phase separation with diethyl ether (5). Milk was additionally defatted with hexane before this procedure (40). The combined ether fractions were dried under nitrogen and redissolved in a 1:1 mixture of acetonitrile–sodium acetate buffer (0.2 mol/L, pH 5). Five to 20 μL of this extract was analyzed by liquid chromatography/PDA/ESI-MS with an LCQ Surveyor-Advantage ion trap system (ThermoElectron Corp, San Jose, CA) equipped with a HydroBond PS C_{18} (100 × 3.0 mm; 5 μm) reversed-phase column coupled to a HydroBond PS C_{18} (25 × 3.2 mm; 5 μm) direct-connect guard column (MacMod Analytic Inc, Chadds Ford, PA). The elution, absorbance detection, and mass spectrometric measurements were performed as applied previously (34, 44, 46, 47). Limits of quantitation for all analytes using 0.3 mL plasma, 1.8 mL milk, or 1.2–1.8 mL urine were 2.5 nmol/L except for dihydrodaidzein and dihydrogenistein (1.5 nmol/L) and O-desmethylangolensin (5.0 nmol/L). Between-day CVs for plasma, milk, and urine ranged from 4% to

TABLE 2
Characteristics of the participants in the soy intervention study[1]

Subjects	Specimen code	n^2	Age	Body weight
				kg
Mothers donating urine	MU	16[3]	32.4 ± 1.8 y[4]	55.3 ± 1.7
Mothers donating milk	MM	16[3]	Same	Same
BF infants donating urine	BU	13[3]	12.0 ± 3.5 wk	4.5 ± 1.1
BF infants donating plasma	IP	11	Same	Same
TF infants donating urine	IU	3	14.3 ± 4.8 mo	11.4 ± 3.2
TF infants donating plasma	IP	3	Same	Same
Mothers donating urine and milk	MU-MM	16[3]	—	—
Mothers donating milk and their BF infants donating urine	MM-IU	12[3]	—	—
Mothers donating urine and their BF infants donating urine	MU-IU	13[3]	—	—
BF infants donating plasma and urine	IP-IU	11	—	—
TF infants donating plasma and urine	IP-IU	3	—	—

[1] BF, breastfed by soy-consuming mothers; TF, tofu fed.

[2] The total number of participants correctly completing the intervention.

[3] Includes 7 participants who also donated baseline samples.

[4] $\bar{x}$ ± SEM (all such values).

12% for daidzein, 5–18% for genistein, and 3–14% for glycitein. Isoflavone metabolites (equol, dihydrodaidzein, dihydrogenistein, and *O*-desmethylangolensin) were not considered here because of amounts at detection limits. Urinary creatinine was measured by using a Roche Cobas MiraPlus clinical autoanalyzer (Roche Diagnostics, Indianapolis, IN) with a kit from Randox Laboratories (Crumlin, United Kingdom) that is based on a kinetic modification of the Jaffe reaction.

Statistical procedures

Student's paired *t* test was applied to test the significance of differences in isoflavones before and after the soy intervention in MU, IU, and MM with the use of EXCEL software 1998 for Macintosh (Microsoft Inc, Redmond, WA). Fisher's *z*-transformation was used to test the statistical significance of the correlation coefficients by using EXCEL software 1998. This transformation allowed us to test any null hypothesis, ie, not just to test whether the true correlation was zero. It is more flexible and appropriate than the *t* test for correlation when the distribution of sample values of the correlation is skewed under the true correlation being nonzero. Means were calculated by using one data point per subject before or after the intervention.

RESULTS

Sixteen mothers correctly complied with the protocol and collected at least one specimen (milk, urine, or plasma). Reasons for missing samples were lack of sufficient volume for analysis (MM, IU) or forgetting to collect (MU). One of the noncompliers forgot to consume the soy beverage; samples for that subject pair were used for baseline measurements only. No data from the other noncomplier were included in the analysis. Three mothers gave their infants soy-based infant formula; therefore, only the mothers' specimens could be included. Mean values were used from each individual when repeated collections were available.

Sixteen mothers correctly completed the collection of MU and MM, and 13 and 11 infant samples were collected for IU and IP, respectively. For specimen pair comparisons, 12 participants completed the protocol correctly for the donation of MM-IU
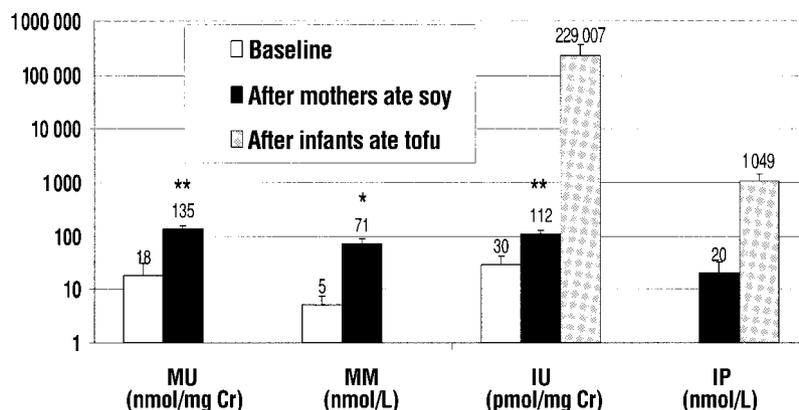
FIGURE 1. Mean (±SEM) urinary isoflavone excretion rates and breast milk and plasma concentrations of isoflavones in mothers' urine (MU), mothers' milk (MM), infants' urine (IU), and infants' plasma (IP). White bars represent the mean values from 7 participants before the mothers consumed soy, and black bars indicate the mean values from these 7 participants after the mothers consumed soy; the black bar for IP illustrates the mean value in 11 breastfed infants. The gray bars depict mean values in 3 tofu-fed infants. Cr, creatinine. *, **Significantly different from baseline: *$P \leq 0.005$, **$P \leq 0.002$ (paired two-tailed *t* test for 7 intervention-baseline pairs).
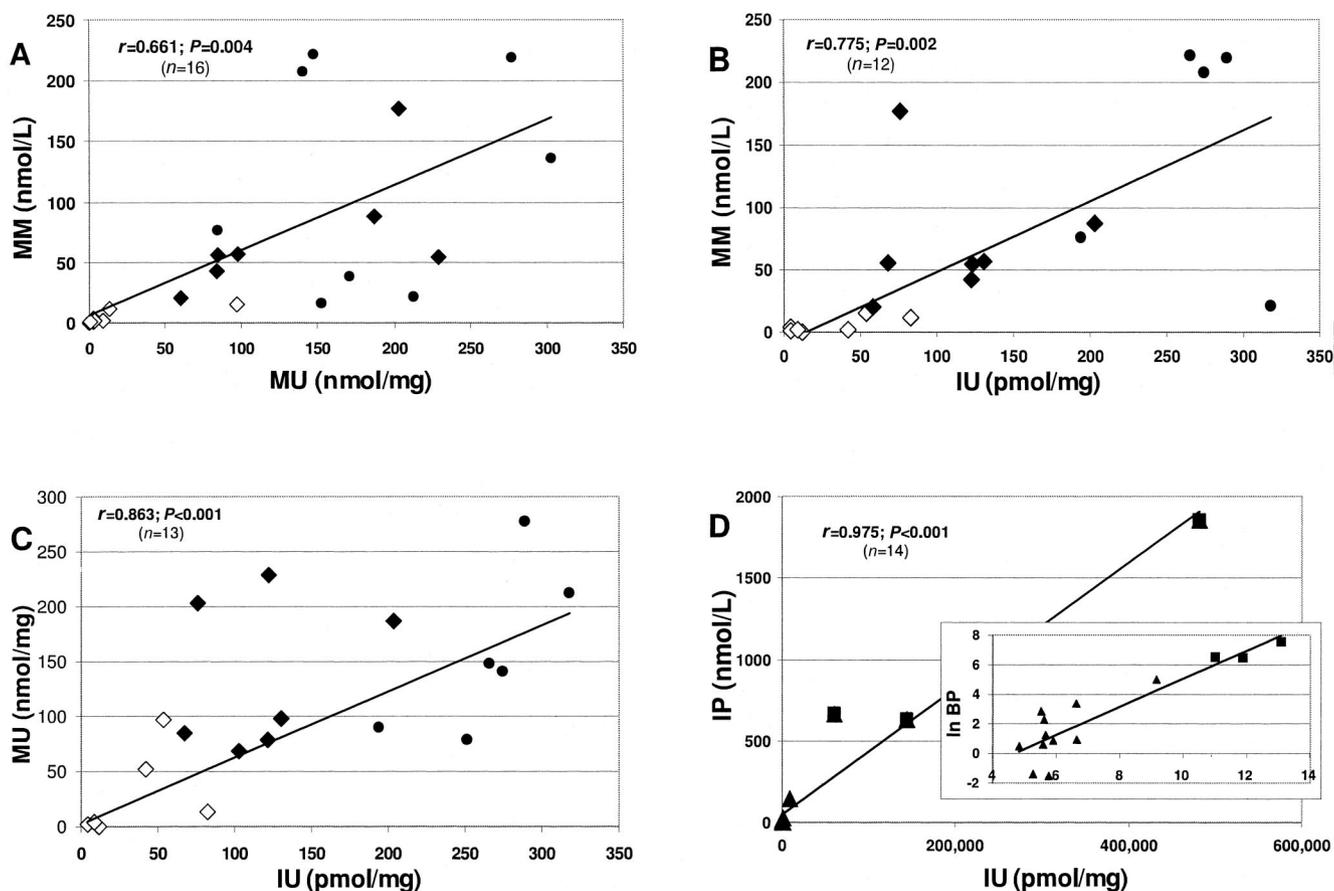
FIGURE 2. Correlations between types of specimens collected from mothers and their infants. The linear regression curve (r = Pearson correlation, P = significance by 2-tailed z test) was generated by using values of 7 participants at baseline (◇), data obtained from these subjects after the mothers consumed soy (◆), and values of 5–9 more participants who delivered samples exclusively after mothers consumed soy (●) (panels A-C). Infant plasma (IP)-urine (IU) pairs of breastfed (▲) or tofu-fed (■) infants are shown in panel D. The linear regression is based on all data shown and was not altered significantly after removal of the 3 data pairs for the TF infants. The insert in panel D shows the values on a natural logarithmic scale. MM, mothers' milk; MU, mothers' urine.

pairs, 13 for MU-IU pairs, 14 for IP-IU pairs (11 BF, 3 TF), and 16 for MU-MM pairs (**Table 2**).

The protocol was challenging for most participants because it required the collection of multiple samples and the timed collection of IU with the use of clinical urine bags and because of the general stress connected with a new baby, particularly for primiparas. Therefore, baseline MU, MM, and IU was obtained from only 7 mother-infant pairs with 3 female and 4 male infants. The mean ($\pm$SEM) values of these 7 subjects before and after the intervention were 18.4 $\pm$ 13.0 and 135.1 $\pm$ 26.0 nmol/mg creatinine (Cr) for MU, 5.1 $\pm$ 2.2 and 70.7 $\pm$ 19.2 nmol/L for MM, and 29.8 $\pm$ 11.6 and 111.6 $\pm$ 18.9 nmol/mg Cr for IU (**Figure 1**). Isoflavone values increased significantly after the intervention in these 7 participants for all the body fluids provided (MU, MM, IU) according to paired Student's t tests. When the data from additional participants who donated specimens exclusively after the intervention were included, the results were similar, ie, mean overall values for MU after the intervention (9 additional mothers consuming soy) were 157.1 $\pm$ 18.5 nmol/mg Cr, those for MM (9 additional mothers consuming soy) were 95.4 $\pm$ 19.6 nmol/L, and those for IU (5 additional BF infants) were 186.1 $\pm$ 25.1 nmol/mg Cr. In IP we found mean total isoflavone concentrations of 19.7 nmol/L (median: 2.5 nmol/L; range: 0.2–148.5 nmol/L) in a total of 11 BF infants. In an additional 3 children aged 9–25 mo who ate 15–90 g tofu, we found much higher mean isoflavone

values of 229 nmol/mg Cr in urine (median: 145 nmol/mg Cr; range: 61–482 nmol/mg Cr) and 1048.6 nmol/L in plasma (median: 663.1 nmol/L; range: 629.1–1853.6 nmol/L). The unexpected and extremely high plasma value of 1.86 μmol/L was obtained from a child (aged 11 mo) who consumed ≈90 g tofu for this study. In addition to passing the exclusion criteria during the recruitment phase, we confirmed with the parents after study completion that this child was not fed any soy formula or soy supplement during or before this study.

Glycitein values were negligible in MM and IP, with a contribution of ≈2% relative to the total isoflavone concentrations. In MU and IU, however, glycitein contributed 9% and 17%, respectively. The daidzein-to-genistein ratio was on average 0.6, 2.4, 1.3, and 0.4 in MM, MU, IU, and IP, respectively. However, in IP of TF infants, this ratio was 1.1 and therefore almost 3-fold that in BF infants.

As shown in **Figure 2**, high correlations were observed between the types of fluids investigated and all were statistically significant according to a two-tailed z test whether within mothers (MM versus MU: r = 0.661), between mothers and infants (MM versus IU: r = 0.775; MU versus IU: r = 0.863), or within infants (IP versus IU: r = 0.975). Correlation coefficients and P values did not change considerably when applying median or logged values (data not shown).

TABLE 3
Doses and appearance of urinary isoflavones in mothers and their infants

Subjects	IFL dose per kg BW	UIE per mg Cr		UIE per hour per kg BW[3]	
		UIE	UIE/dose[3]	UIE	UIE/dose[4]
	mg/kg	*nmol/mg Cr*		*nmol · h⁻¹ · kg⁻¹*	
Mothers ($n = 16$)	1.01 ± 0.03[5]	157.1 ± 18.5	156.0 ± 18.7	137.5 ± 16.2	136.5 ± 16.3
BF infants ($n = 13$)	0.003 ± 0.0002	0.186 ± 0.025	60.0 ± 7.8	0.08 ± 0.01	25.5 ± 3.3[6]
Relative to mothers (%)	0.3	0.1	38.5	0.1	18.4
TF infants ($n = 3$)	0.694 ± 0.42	229.0 ± 128.7	344.6 ± 65.4	112.6 ± 63.3	169.4 ± 32.1[7]
Relative to mothers (%)	68.8	145.8	220.9	81.9	124.1

[1] Means of data from all available specimens were used; 125 mL milk intake per kg BW per day by BF infants was assumed (48). IFL, isoflavone; BW, body weight; UIE, urinary isoflavone excretion; Cr, creatinine; BF, infants breastfed by soy-consuming mothers; TF = tofu-fed infants (not breastfed).

[2] Conversion via daily urinary Cr excretion per kg BW (mg/kg) of 21, 10.2, and 11.8 for mothers (mean BW = 55 kg), BF infants (mean BW = 4.5 kg), and TF infants (mean BW = 11.4 kg), respectively (64).

[3] (nmol/mg Cr)/(mg · kg⁻¹ · d⁻¹).

[4] (nmol · h⁻¹ · kg⁻¹)/(mg · kg⁻¹ · d⁻¹).

[5] $\bar{x} \pm$ SD (all such values).

[6] Significantly different from mothers, $P < 0.001$ (2-tailed unpaired t test).

[7] $P = 0.43$ for difference from mothers by 2-tailed unpaired t test.

To compare urinary isoflavone excretion (UIE) between infants and their mothers relative to dose (**Table 3**), we used the known isoflavone dose in mothers (55 mg/d), the established assumption of daily breast milk intake of 100–150 mL/kg body wt of infants (48), and the measured isoflavone dose of 7.37 mg in tofu (43) based on the amount fed (≈44 g) according to the mothers. This resulted in a dose per body weight of 1.01 mg/kg in mothers on the basis of their mean body weight of 55 kg, 0.003 mg/kg in BF infants on the basis of the isoflavone concentration in breast milk of 95 nmol/L (Figure 1), and 0.69 mg/kg for the 3 TF infants on the basis of their individual weights. Relative to their mothers, this body weight–adjusted dose is 69% in TF infants but only 0.3% in BF infants.

UIE adjusted for creatinine concentration was found to be 157, 0.186, and 229 nmol/mg Cr, and when adjusted to dose per kg body wt, these values changed to 156, 60, and 345 (nmol/mg Cr)/(mg · kg⁻¹ · d⁻¹) in mothers, their BF infants, and TF infants, respectively (Table 3). Relative to their mothers, this creatinine-based UIE-dose ratio was less than one-half in BF infants but >2-fold higher in TF infants.

The daily creatinine excretion in urine can vary greatly between individuals but is mainly determined by sex, age, and body weight (49, 50). Under consideration of these factors, an accurate conversion of creatinine-based urinary excretion rates to hourly urinary excretion rates was performed by using established values for daily creatinine excretion per kg body wt, ie, 21.0, 10.2, and 11.8 mg in mothers (aged 28–36 y), BF infants at a mean age of 2 mo, and TF infants at a mean age of 15 mo, respectively (49–51). Our measured creatinine-based UIE values converted in this process to hourly UIE of 138, 0.08, and 113 nmol · h⁻¹ · kg⁻¹, respectively (Table 3). When these body weight–adjusted hourly UIE values were additionally adjusted to dose per kg body wt (UIE/dose; Table 3) they changed to 137, 26, and 169 (nmol · h⁻¹ · kg⁻¹)/(mg · kg⁻¹ · d⁻¹) for mothers, their BF infants, and TF infants, respectively. Relative to their mothers, this body weight– and time-adjusted UIE/dose ratio was found to be ≈81% lower in BF infants but 24% higher in TF infants, with the former but not the latter value reaching statistical significance.

DISCUSSION

We found low circulating concentrations and urinary excretion rates of isoflavones in breastfed infants of mothers who consumed usual servings of a soy protein drink despite the presence of these isoflavones as glucuronide and sulfate conjugates, which are easily hydrolyzed to bioavailable aglycons. This finding was probably due to the very low isoflavone dose but also to a lower ability of isoflavone uptake relative to adults when adjusted to dose. In contrast, TF infants showed high isoflavone amounts in plasma and urine, which exceeded those found in adults eating soy. This indicates that the isoflavone conjugation pattern alone does not determine isoflavone uptake capacities in children.

As expected, there was a significant increase in isoflavone amounts between baseline and the soy intervention in mothers (8-fold in MU and 14-fold in MM) but also in their BF children (4-fold in IU). When we included the 5 to 9 participants without baseline samples, the combined mean values after soy intervention were similar, and the differences were most likely due to the known interindividual variability in isoflavone uptake (35, 52). Isoflavone values in TF infants' plasma and urine were on average 53-fold and >1200 times the values in BF infants, respectively. Concentrations of this magnitude in children were previously thought to exist only in soy formula–fed infants, who are exposed to very high isoflavone doses (6–8 mg/kg body wt) (36, 42). Plasma isoflavone concentrations in adults were found to peak at 1.5 μmol/L after 27 mg isoflavone (6) or 10–50 nmol/L per mg isoflavone consumed (reviewed in reference 10), with less efficient uptake at greater doses (53). Our findings in TF infants were much higher, 135 nmol · L⁻¹ · mg⁻¹, and may have even been greater because our collections might not have coincided with peak plasma isoflavone concentrations. These findings suggest a higher isoflavone exposure in children than in adults, particularly when considering that children eat more per kg body wt. This might shed a different light on isoflavone effects. High soy consumption in some Asian countries may lead to high systemic isoflavone exposures in Asian children. The low

breast and prostate cancer risk in these populations (reviewed in references 54 and 55) may be due to high systemic isoflavone exposure. Phytoestrogens may act as selective estrogen receptor modulators, which, like steroidal estrogens, have been found to have preventive effects on breast cancer during early periods in life through the up-regulation of tumor suppressors, increases in breast cell differentiation, and other mechanisms (56–58). This hypothesis agrees with epidemiologic findings of reduced breast cancer risk later in life when soy is consumed during early ages (59, 60).

We observed high correlations in isoflavone concentrations between the types of fluids investigated. These statistically significant *r* values indicate that isoflavones *1*) are secreted into milk at similar rates as they are excreted into urine in lactating women, *2*) are taken up from breastfeeding infants in a linear dose-dependent manner, and *3*) appear in BF infants to a similar extent in plasma as they do in urine. The latter finding agrees with recent reports in adults after consideration of accurate timing for sample collections and of different plasma:urine ratios for each individual isoflavonoid (6, 14, 18, 61). Our findings in children are noteworthy, because urinary isoflavone analysis can serve as a surrogate for measuring systemic isoflavone exposure, which avoids invasive blood draws that are particularly difficult to obtain from healthy minors. Similarly, isoflavones in the urine or milk of mothers are good surrogates for their infants' isoflavone exposure. Consequently, mothers' specimens might be sufficient for obtaining reliable estimates of isoflavone exposure in BF infants.

When urinary excretion is expressed by adjusting for urinary creatinine concentrations, it is important to consider that the latter depends mostly on muscle mass and, consequently, largely on body weight, sex, and age (49, 50). This is particularly relevant when comparing children and adults (50), not only because of marked changes in muscle mass in the growing child in absolute terms but also after adjustment for body weight (50, 62–64). We converted measured UIE, which was adjusted for creatinine concentrations, into UIE adjusted for time (hour) by applying established correction factors that take into account body weight, sex, and age (50). Urinary excretion rates adjusted solely for creatinine underestimate true excretion in heavier individuals—for example, in males versus females or in older children versus younger children—and lead to erroneous results (51). The lack of conversion to time-based urinary excretion rates might explain the lower UIE in older than in younger soy-exposed children reported by others (65) or the loss of differences in urinary sex steroid excretion in females of different reproductive ages (66). When we converted UIE to time-based values and additionally adjusted for dose per kg body wt, the UIE/dose ratio changed in infants by a factor of ≈2, whereas that in adults changed little. The low isoflavone values in BF infants were unexpected because it was hypothesized that the isoflavone glucuronides and sulfates as present in breast milk (40, 41) are more bioavailable to the infant than the beta glucoside conjugates present in soy food (6, 43) because of the intrinsic enzymatic capacity to hydrolyze the former, whereas the latter conjugates require mainly intestinal bacteria for hydrolysis (6). Our hypothesis was based on the fact that β-glucuronidase is present in humans in many biological fluids and in almost all tissues, with especially high activity in liver, kidney, spleen, endocrine and reproductive organs, and the intestinal epithelium (67–69; for review, *see* reference 70).

The low isoflavone values in urine and plasma of BF infants, even after consideration of the low dose, could be due to the impaired ability of the nonmatured gut flora to cleave glucuronide and sulfate conjugates for the production of the aglycons required for isoflavone uptake. However, the constant exposure to isoflavone in infants breastfed by mothers regularly consuming soy will result in more uniform systemic concentrations, and bioavailability as measured by area under the curve might be higher than single isoflavone plasma concentrations indicate. Nevertheless, although detectable isoflavone concentrations were measured, the urine and plasma values in infants exposed to isoflavone-containing breast milk were low but might still be in the pharmacologically relevant range. Conversely, the higher isoflavone bioavailability after soy intake in weaning infants relative to adults could be due to the maturing gut flora that has attained the ability to hydrolyze beta glucosides efficiently (6) for the production of aglycons but has not yet developed fully to degrade unconjugated isoflavones (71). This would result in an overall higher survival of ready-for-uptake isoflavone aglycons in the gut (52). Despite similar isoflavone doses per kg body wt through adjustment of soy doses, we found higher creatinine-based UIE in 8–14-y-old girls than in adults (72), and this difference was little changed after conversion to hourly UIE (G Maskarinec, unpublished observations, 2005). This agrees with the present findings and supports our hypothesis of higher isoflavone bioavailability in children than in adults. Collection of the entire urine amount in a timed fashion bypasses the need for conversion of creatinine-based UIE; although 24-h (or longer) urine collections result in very precise data, a protocol of this nature is often difficult or impossible to perform in human studies for various reasons. A good compromise is the collection of overnight urine, which resulted in very high compliance previously (2, 73) and which is particularly recommended for research in children once bladder control is achieved.

Weaknesses of this study are the small sample size and the lack of control over infants' sample collections. In addition, all specimens were collected in a 1–2-h time period in the afternoon after the mothers had consumed their soy dose in the morning. This time frame could lead to major differences in isoflavone appearance in plasma, urine, or breast milk as a result of the fast isoflavone pharmacokinetics (7–9, 40). Correlations between the various types of fluids analyzed could probably be improved with a more uniform and defined schedule for soy consumption, breastfeeding, and sample collections. With this in place, changes in uptake in infants as a function of age could be evaluated. Despite the relatively small number of samples in this study, we obtained robust results considering the insignificant change in all correlation coefficients and *P* values when applying median or logged values. To our knowledge, this is the first report on isoflavone values in urine and plasma of infants who were breastfed by soy-consuming mothers or who ate tofu. It adds critical information to the previous animal and recent epidemiologic studies showing beneficial effects of soy exposure by elucidating isoflavone appearance in humans at an early age. The current study shows that, independent of relative bioavailability, isoflavone exposure in soy-consuming populations is probably higher in children than in adults, particularly as a result of larger intake when adjusted for body weight.

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