Reproducibility and Relative Validity of a Questionnaire to Assess Intake of Black Tea Polyphenols in Epidemiological Studies[1]

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Abstract

Epidemiological studies suggest that tea drinking may reduce the risk of cardiovascular diseases and cancers. Although tea is an important source of antioxidant phytochemicals, variation in preparation techniques may translate to variation in antioxidant capacity. However, most large-scale epidemiological studies use regular food frequency questionnaires to estimate tea intake, and nationally available nutrient analysis databases do not include levels of black tea polyphenols. The Arizona Tea Questionnaire (ATQ) was designed as a tool for collecting more complete dietary tea consumption information, and a database was developed after analyzing 40 black tea samples (brewed, instant, and sun tea) for polyphenols. This study assesses the reliability and relative validity of the ATQ and polyphenol database. Relative validity of estimates of black tea consumption was tested by comparing the ATQ with the traditional Arizona Food Frequency Questionnaire and four days of food records. The ATQ was tested for reproducibility of estimates of black (hot and iced) tea consumption and levels of black tea polyphenol intake. Correlations between two measures of intake taken 2 months apart ranged from 0.72 for black hot tea to 0.86 for black sun tea. Mean intakes (range) of total flavonoids for black tea consumers were 80.8 (3.0–588.0) mg/day at the first ATQ and 102.4 (4.5–802.3) mg/day at the second ATQ ($r = 0.83$, $P < 0.001$). The ATQ provided highly reproducible estimates of both total tea consumption and individual tea polyphenol intake. This instrument may be a useful tool in studies of the associations between tea consumption, tea polyphenols intake, and risk for chronic disease.

Introduction

The popularity of tea has stood the test of time. Today, tea is enjoyed around the world, and its consumption reflects local preferences and traditions. For the past two decades, epidemiologists have observed lower risks of cancer (1–3), cardiovascular diseases (4–6), and osteoporosis (7–9) in populations that drink tea frequently. However, although epidemiological evidence of health benefits associated with tea consumption is equivocal, experimental studies *in vitro* and with animals had repeatedly linked tea extracts to reduced risk of cancer and cardiovascular disease. Of particular interest are the accumulating data that reflect similar health benefits associated with both the epicatechins of green tea and the theaflavins and thearubigens of black tea (10).

Tea provides a natural source of antioxidant phytochemicals. Flavonoids, as a class of antioxidants, constitute the relative majority (36%) of compounds of the leaves of *Camellia sinensis* (11). Tea, whether black, green, or oolong, is the richest source of flavonoids in the Northern European diet, more so than regular servings of fruits or vegetables (6, 12). Most large-scale epidemiological studies use food frequency questionnaires to estimate tea intake. However, most food frequency questionnaires do not take into account variation in tea preparation. Because dry tea leaves are not consumed directly, brewing conditions (time and strength) may influence the final antioxidant capacity in the tea as consumed.

Increasing recognition of the potential importance of phytochemicals in the etiology of various diseases has highlighted the need for methods to measure individual phytochemical consumption that are sufficiently simple to be used in large epidemiological studies and whose reproducibility and accuracy have been quantified. We demonstrated recently that brewing time, strength of tea, and temperature of the tea result in variable levels of total polyphenols and flavonoids (13). We also demonstrated a potential association between strong (hot) tea consumption and decreased incidence of squamous cell carcinoma of the skin (14).

In this study, we report the relative validity of the ATQ[3] and the reproducibility of ATQ estimates for black (hot and iced) tea consumption and for total tea polyphenols intake among 120 individuals.

Materials and Methods

ATQ. We designed the ATQ (see Appendix) to serve as a supplement to the AFFQ and to categorize individuals by intake of tea and the specific tea polyphenols. The questionnaire was developed after focus groups identified usual patterns of tea consumption. Information was considered on how often sub-

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[3] The abbreviations used are: ATQ, Arizona Tea Questionnaire; AFFQ, Arizona Food Frequency Questionnaire; EC, epicatechin; ECG, epicatechin gallate; EGC, epigallocatechin; EGCG, epigallocatechin gallate; FR, food record.

jects consumed various tea products (black tea, green tea, and herbal tea). Frequency and portion size of hot and iced black tea and hot and iced green tea consumption were asked separately for summer and winter. Participants identified their usual tea preparation recipes by indicating: (*a*) brewing time; (*b*) number of tea bags or teaspoon(s) used per cup for hot tea and per a half gallon for iced tea; (*c*) preferred strength and temperature for hot tea (warm or hot) and iced tea (cold or with ice); (*d*) percentage of use of decaffeinated tea; and (*e*) additives to the tea (sweetener, milk, citrus, or spices). Detailed information was sought for consumption of sun tea, instant tea, and bottled tea products.

In 1998, this questionnaire was tested for short (1 week) and long-term (6 months) reliability within a randomly selected sample of men ($n = 20$) and women ($n = 20$) between the ages of 40 and 80 years who had participated previously in a study of skin cancer. All individuals completed phone interviews at baseline, 1 week, and 6 months. Reproducibility for each of the specific questions was very high, even at 6 months, ranging between 0.90 and 0.98 (13, 14).

The ATQ is now available in an optical, scannable format to provide raw computer files for subsequent analysis (see Appendix). For each black tea type on the ATQ, the black tea polyphenols database contains the corresponding levels (μg/ml) for total flavonoids, total polyphenols, catechins (EC, ECG, EGC, and EGCG), theaflavins, thearubigens, gallic acid, and caffeine. On average, it took the subjects 7 min to fill out the questionnaire.

Development of the Black Tea Polyphenols Database and the Computer Program. Nationally available nutrient databases did not include tea polyphenols. Therefore, we analyzed 40 samples, representing common recipes for black tea beverages, for levels of various polyphenols to develop a preliminary database for tea polyphenols at the Arizona Cancer Center. This preliminary Arizona Cancer Center database is based on analysis of 18 hot and 22 iced black tea beverages. Levels of total polyphenols, flavonoids, catechins (EC, ECG, EGC, and EGCG), theaflavins, thearubigens, gallic acid, and caffeine were averaged for each type of tea by leaf concentration (regular or diluted) and brewing time (1, 2–3, and ≥4 min) for hot tea and preparation technique for iced tea (brewed, sun tea, instant tea, and restaurant). The detailed methodology for preparation and analysis of the tea samples is described elsewhere (13).

An analysis program then merged dietary data from the ATQ with the tea polyphenol database to estimate total flavonoids, total polyphenols, catechins, theaflavins, thearubigens, gallic acid, and caffeine intake/day. Forms were entered using an interactive screen input program written in SAS (15), and programs were written to summarize estimates of total intake of specific polyphenols. For each type of tea preparation (bags, loose, instant, and bottled/canned), frequency of summer and winter use was averaged to estimate consumption (times/day) over the past year. Estimates (ml/day for iced and hot tea) were modified by the relative percentage of use of each specific tea preparation type (bags, loose, instant, bottled/canned, or sun tea) calculated in this step and were drawn from the amount of bags or loose tea that was consumed for iced tea and the strength of tea. The tea polyphenols database was merged with the consumption data to estimate the μg/ml of each polyphenol type (total flavonoids, catechins, theaflavins, thearubigens, gallic acid, and caffeine) for each type of tea preparation. Lastly, ml/day of the tea consumed was used to determine the μg/day of each polyphenol.

The program creates two datasets, a detail file and a summary file. The detail file of dietary polyphenols (μg/day) contains one record for each tea preparation type for each participant. The summary file creates one record/participant and contains the sum of total polyphenols, total flavonoids, catechins, theaflavins, thearubigens, gallic acid, and caffeine/day (μg/day) from all tea preparation types.

Assessment of the Reliability and Validity of the ATQ and Database. For study design and data collection, we tested the ATQ for reliability and relative validity among 120 healthy subjects (ages 40–82 years) participating in an ongoing 6-month skin biomarker study. Data collection started in February 1999 and took 12 months. All subjects completed the usual AFFQ, 4 days of FRs, and the two ATQs. AFFQ was administered at baseline, whereas the ATQ was administered 1 week before (ATQ1) and 6 weeks after the last diet record was completed (ATQ2). All questionnaires were self-administered. Processing of the questionnaires and food records were conducted by the Nutrition Core at the Arizona Cancer Center. The quality control/quality assurance procedures included 25% duplicate entry of food records with all coders completing a formal training and probationary period. The AFFQ was optically scanned with a quality control/quality assurance procedure to double scan each AFFQ. Generic food frequency analysis software was written using an expansion and enhancement of the Block nutrient database (16) to report totals of all nutrients and subtotals within food groups.

Statistical Analyses. Relative validity was assessed by comparing the data collected from the tea questionnaire with that drawn from the baseline AFFQ and food records. Reliability was assessed by comparing the estimates from ATQ1 and ATQ2. For each questionnaire (AFFQ, ATQ1, and ATQ2), the percentage of participants who consumed tea, as well as the median, the 25th and 75th percentiles of tea (ml/day) among consumers were calculated. Pearson and Spearman correlation coefficients were estimated between total intake (ml/day for black tea) from the ATQ1, AFFQ, and FRs. Similarly, Pearson and Spearman correlation coefficients between the log-transformed estimates (ml/day for black tea and mg/day for black tea polyphenols) from ATQ1 and ATQ2 were calculated. Because results were of similar magnitude, we reported Pearson correlation results. Precision was examined using intraclass correlation coefficients between the log-transformed (natural log) estimates of black tea polyphenols for the two tea questionnaires (ATQ1 and ATQ2).

To compare absolute intake levels of hot and iced tea, sample medians and 25th and 75th percentiles were computed, and reproducibility was assessed by examining differences between ATQ1 and ATQ2, using the sign test and Wilcoxon sign rank test to test differences in distributions. Statistical significance was defined as two-sided $P \leq 0.05$. Because both results were identical, we reported the Wilcoxon sign rank results. All statistical analyses were done using STATA computer software (17).

Results

The preliminary black tea polyphenol database used in this study is presented in Table 1. Our data show that tea leaf concentration and brewing time have major influences on flavonoid and polyphenol concentrations in hot tea beverages. Similarly, the concentration of flavonoids and polyphenols varies considerably, depending on the method of preparation of iced tea beverages.

The ATQ was tested for reliability and relative validity

Table 1 Black tea polyphenol database based on the composition of commonly consumed black tea beverages in Arizona

	No. of samples	Average concentration (μg/ml)						
		Total flavonoids	Total polyphenols	Catechins	Theaflavins	Thearubigens	Gallic acid	Caffeine
Regular hot black tea[a]								
Brewed for 1 min	3	417	642	40	0	377	17	145
Brewed for 2–3 min	6	648	997	94	13	546	27	244
Brewed for ≥4 min	3	692	1064	87	15	585	25	215
Diluted hot black tea[b]								
Brewed for 1 min	2	183	282	10	0	173	3	62
Brewed for 2–3 min	2	222	341	15	0	207	4	79
Brewed for ≥4 min	2	361	555	23	0	338	8	103
Iced black tea beverages								
Brewed	10	507	779	74	8	369	18	158
Sun Tea	5	383	589	47	3	333	21	131
Instant	2	96	147	1	0	95	3	30
Restaurant	5	470	724	40	3	425	32	200

[a] One tea bag/cup or mug = 0.96 g of tea leaves/100 ml.
[b] One tea bag/2 cups or 2 mugs = 0.48 g of tea leaves/100 ml.

Table 2 Descriptive data and daily median (P25, P75) tea intake as estimated by the ATQ (ATQ1),[a] the AFFQ, and 4 days of FRs

	% consuming $n = 116$[b]	Tea intake for consumer (ml/day)		r_i[d]
		Median (P25, P75)[c]	Mean (SD)	
ATQ1[a]	78.3	48.8 (24.0, 155.2)	126.6 (154.8)	
AFFQ	87.9	44.1 (13.7, 129.7)	111.8 (182.5)	0.97
FRs	69.4	88.8 (59.3, 118.4)	101.1 (56.7)	0.77

[a] ATQ1, first administration of the ATQ. P25, P75, 25th and 75th percentiles.
[b] Four subjects had incomplete food records (<4) and were excluded from the analysis.
[c] Two-sided Wilcoxon signed-rank test comparing intake (ml/day) based on AFFQ and FRs with that based on ATQ_1 = no statistical significant difference.
[d] r_i = intraclass correlation coefficient for log-transformed data.

among 120 healthy subjects (ages 40–82 years) participating in an ongoing 6-month skin biomarker study. More than 90% of the participants were non-Hispanic whites, nonsmokers, and 84% of them had at least some college education. The mean age of study participants was 60 years (+10.1 years) with men (47.5%) and women (52.5%) represented equally. The mean energy intake of the subjects was 1833.6 (+787.6) Kcal/day, with 33.1% (+10.9%) of calories from fat.

Descriptive information regarding total amount of tea intake/day as estimated from the various methods (ATQ, AFFQ, and FRs) is presented in Table 2. The tea intake estimates were based on reported frequencies and reported portion sizes. On average, 70% of the participants reported drinking black tea beverages during the past year. The intraclass correlation coefficients for the amount of tea intake (log-transformed) between the methods were 0.97 (ATQ1 and AFFQ) and 0.77 (ATQ1 and FRs). Daily median intakes for total tea consumption (ml/day) estimated by ATQ1, AFFQ, and FRs are also given in Table 2. Two-sided Wilcoxon signed-rank test showed no statistically significant differences among the three methods. Although there was variation in the range of intake and skewness of the data, the Spearman's correlations were of the same magnitude as the Pearson's correlations.

Overall, the 2-month reproducibility of the ATQ was high and ranged from 0.66 for amount of iced tea intake to 0.92 for hot tea. The reproducibility of the various tea polyphenols (μg/ml) ranged from 0.78 to 0.85 (using either Pearson or Spearman correlation). Two-sided Wilcoxon signed-rank test showed no statistical significant difference between the two administrations (data not shown).

Table 3 shows estimates of levels of tea polyphenols intake among black tea consumers as measured at the two ATQ surveys. Pearson correlation coefficients for the log-transformed daily intake (mg/day) of tea polyphenols by type of tea consumed between the two administrations of the ATQ ranged from 0.67 for restaurant iced tea to 0.81 for sun tea. Daily median intakes for tea polyphenols (mg/day) from black tea assessed by ATQ1 and ATQ2 are also shown in Table 3. For these black tea beverages, the polyphenols estimates were based on reported frequencies and portion sizes. Two-sided Wilcoxon signed-rank test showed no statistical significant difference between the two administrations of the ATQ.

Discussion

A recent focus in nutrition epidemiology has been on evaluation of the role of food groups and phytochemicals in chronic disease prevention. For large-scale epidemiological studies, food frequency questionnaires are often the method used to obtain dietary exposure data. Short-term recall and diet records methods are generally expensive, often unrepresentative of usual intake, and inappropriate for assessment of past diet. Studies of the potential relationship between tea consumption and chronic disease typically use food frequency questionnaires to estimate tea intake. The amount of tea estimated from the usual number of cups consumed is frequently then used as the marker of tea and/or polyphenols consumption. However, this may be an inadequate measure of intake because drinking practices of tea vary considerably among and between populations. More focused questionnaires may be needed to assess tea preparation techniques.

Tea leaves are primarily manufactured as green or black or oolong, with black tea representing ~80% of the tea consumed. Catechins and theaflavins are the two major groups of tea flavonoids. The major components of black tea are theaflavins (1–3% dry weight) and thearubigens (10–40% dry weight). Our database show that tea composition, including catechins, varies with tea leaf concentration, brewing time, and beverage temperature. In hot black tea, the total phenolic concentration, and hence, the antioxidant activity increased with the brewing time and tea leaf concentration. Moreover, the wide variability in preparation techniques of iced tea was translated into corresponding variability in tea composition in the resulting tea

Table 3 Daily median (P25, P75) black tea (ml/day) and black tea polyphenols (mg/day) intake as estimated by the ATQ administered twice

Black tea	Daily intake for consumer of product Median (P25, P75)[a]		r_p[b]	r_i[c]
	ATQ_1	ATQ_2		
Overall tea intake (ml/day)	35.52 (11.83, 132.64)	67.59 (21.69, 232.34)	0.68	0.55
Total flavonoids (mg/day)	8.52 (2.91, 32.98)	11.21 (4.60, 44.17)	0.77	0.72
Total polyphenols (mg/day)	13.04 (4.49, 50.56)	17.24 (7.08, 67.87)	0.77	0.72
Catechins (mg/day)	0.94 (0.24, 4.36)	1.12 (0.51, 5.34)	0.82	0.67
Theaflavins (mg/day)	0.13 (0.04, 0.53)	0.14 (0.05, 0.68)	0.76	0.83
Thearubigens (mg/day)	7.03 (2.60, 27.25)	9.59 (4.14, 35.91)	0.77	0.73
Gallic acid (mg/day)	0.37 (0.13, 1.35)	0.48 (0.22, 2.00)	0.77	0.68
Caffeine (mg/day)	2.77 (1.03, 11.58)	3.77 (1.66, 15.98)	0.77	0.69
Hot tea (ml/day)	23.45 (8.87, 81.32)	25.63 (13.31, 211.21)	0.67	0.58
Total flavonoids (mg/day)	12.32 (4.47, 75.28)	13.25 (5.94, 126.26)	0.72	0.82
Total polyphenols (mg/day)	18.95 (6.88, 115.82)	20.38 (9.14, 194.26)	0.72	0.82
Catechins (mg/day)	1.56 (0.65, 9.29)	1.78 (0.83, 15.97)	0.70	0.81
Theaflavins (mg/day)	0.15 (0.05, 0.71)	0.23 (0.11, 1.37)	0.76	0.79
Thearubigens (mg/day)	10.38 (3.77, 63.43)	11.19 (5.02, 106.39)	0.72	0.83
Gallic acid (mg/day)	0.51 (0.19, 3.04)	0.51 (0.24, 5.26)	0.72	0.82
Caffeine (mg/day)	4.64 (1.68, 2.61)	4.50 (2.16, 47.54)	0.72	0.82
Brewed iced tea (ml/day)	84.49 (15.77, 84.49)	116.17 (23.66, 337.94)	0.71	0.40
Total flavonoids (mg/day)	30.50 (4.50, 57.83)	29.41 (8.00, 96.38)	0.79	0.80
Total polyphenols (mg/day)	46.86 (6.91, 88.85)	45.19 (12.29, 148.08)	0.79	0.80
Catechins (mg/day)	4.45 (0.66, 8.44)	4.29 (1.17, 14.07)	0.79	0.80
Theaflavins (mg/day)	0.48 (0.07, 0.91)	0.46 (0.13, 1.52)	0.79	0.80
Thearubigens (mg/day)	22.20 (3.27, 42.09)	21.41 (5.82, 70.14)	0.79	0.80
Gallic acid (mg/day)	1.08 (0.16, 2.05)	1.04 (0.28, 3.42)	0.79	0.80
Caffeine (mg/day)	9.50 (1.40, 18.02)	9.12 (2.49, 30.03)	0.79	0.80
Sun tea (ml/day)	33.79 (11.83, 152.07)	50.69 (21.69, 253.46)	0.81	0.76
Total flavonoids (mg/day)	6.63 (2.98, 25.40)	6.80 (4.53, 24.27)	0.81	0.87
Total polyphenols (mg/day)	10.20 (4.58, 39.06)	10.45 (6.97, 37.32)	0.81	0.87
Catechins (mg/day)	0.81 (0.37, 3.12)	0.83 (0.56, 2.98)	0.81	0.87
Theaflavins (mg/day)	0.05 (0.02, 0.20)	0.05 (0.04, 0.19)	0.81	0.87
Thearubigens (mg/day)	5.77 (2.59, 22.09)	5.91 (3.94, 21.10)	0.81	0.87
Gallic acid (mg/day)	0.36 (0.16, 1.39)	0.37 (0.25, 1.33)	0.81	0.87
Caffeine (mg/day)	2.27 (1.02, 8.69)	2.32 (1.55, 8.30)	0.81	0.87
Instant iced tea (ml/day)	20.70 (11.83, 184.74)	121.45 (34.78, 168.97)	0.64	0.43
Total flavonoids (mg/day)	0.68 (0.43, 8.52)	4.18 (0.91, 11.71)	0.79	
Total polyphenols (mg/day)	1.05 (0.65, 13.04)	6.40 (1.40, 17.93)	0.79	
Catechins (mg/day)	0.01 (0.004, 0.09)	0.04 (0.01, 0.12)	0.79	
Theaflavins (mg/day)	0 (0, 0)	0 (0, 0)		
Thearubigens (mg/day)	0.68 (0.42, 8.43)	4.14 (0.90, 11.59)	0.79	
Gallic acid (mg/day)	0.02 (0.001, 0.27)	0.13 (0.03, 0.37)	0.79	
Caffeine (mg/day)	0.21 (0.13, 2.66)	1.31 (0.29, 3.66)	0.79	
Restaurant iced tea (ml/day)	15.77 (11.83, 50.13)	26.61 (21.69, 126.73)	0.53	0.20
Total flavonoids (mg/day)	5.56 (2.91, 17.87)	7.99 (4.17, 22.34)	0.67	0.32
Total polyphenols (mg/day)	8.56 (4.49, 27.51)	12.31 (6.42, 34.41)	0.67	0.32
Catechins (mg/day)	0.47 (0.25, 1.52)	0.68 (0.36, 1.90)	0.67	0.32
Theaflavins (mg/day)	0.04 (0.02, 0.11)	0.05 (0.03, 0.14)	0.67	0.32
Thearubigens (mg/day)	5.03 (2.63, 16.16)	7.23 (3.77, 20.20)	0.67	0.32
Gallic acid (mg/day)	0.38 (0.20, 1.22)	0.54 (0.28, 1.52)	0.67	0.32
Caffeine (mg/day)	2.37 (1.24, 7.60)	3.40 (1.77, 951)	0.67	0.32

[a] Two-sided Wilcoxon signed-rank test comparing intake (mg/day) based on ATQ_2 with that based on ATQ_1 = no statistical significant difference. ATQ_1, first administration of the ATQ; ATQ_2, second administration of the ATQ (2 months later).
[b] r_p = Pearson correlation coefficient for log-transformed data.
[c] r_1 = intraclass correlation coefficient for log-transformed data.

beverages. One cup of black tea, brewed using one tea bag (regular strength), has approximately three times the amount of total flavonoids and six times the amount of catechins as the same volume prepared by two successive brews of loose tea leaves (diluted). Similarly, one glass of brewed black iced tea has approximately five times the amount of total flavonoids available in a similar glass of instant iced tea. Moreover, instant iced tea contains negligible amounts of catechins. These differences should be accounted for by the epidemiological studies evaluating the effect of tea on health.

There is a need for methods to measure long-term dietary intake with adequate accuracy and reproducibility. The relative validity of food group intake is reported less often than that of nutrient intake. In the present study, the relative validity and the reproducibility of habitual tea intake, estimated by a detailed tea questionnaire (ATQ) are explored. In this study, agreement between the ATQ and other methods is good. Moreover, the ATQ provided highly reproducible estimates of tea consumption and tea polyphenols intake.

The intraclass correlation between the ATQ and 4 days of dietary records observed in the current study was in the reasonable range (0.77) but relatively lower than that for the AFFQ

and ATQ (0.97). This difference can be attributed to large day-to-day variation in tea intake. Thus, although 4-day dietary records or recalls are often used as criterion standards to validate dietary instruments, their inherent inability to capture usual intake will limit, and likely underestimate, the correlations between multiple records/recalls and the ATQ. The day-to-day variability is especially high for the amount (ml/day) of iced tea intake in the hot season and for the intake of instant and restaurant (multiple refills) iced tea. In contrast, food frequency questionnaires usually estimate diet intake over several weeks, so that day-to-day variation plays a minor role. The correlation between larger time periods will then be higher as seen in this evaluation.

For epidemiological applications, the capability of a questionnaire to categorize or rank individual subjects by level of their actual intake is viewed as an essential characteristic (18). Determination of associations between tea polyphenol levels and disease requires accurate ranking of individuals into quantiles of intakes but not necessarily accurate assessment of absolute intake. This ranking ability can be evaluated by using Spearman's correlation and/or Wilcoxon signed-rank test. However, it has also been advocated that to evaluate the magnitude of purported health problems, dietary instruments should estimate absolute intakes. Pearson correlation reflects the degree of agreement between the absolute levels of estimates. In the present study, no clear discrepancies were observed between Pearson and Spearman's correlations (data not shown). In addition, the two-sided Wilcoxon signed-rank test showed no statistically significant differences between the three dietary methods or the two administrations of the ATQ.

Many studies have examined reproducibility over time of nutrient intakes estimated using food frequency questionnaires. These studies have found correlation coefficients ranging from 0.5 to 0.8 (19–22). In our study, the correlations between the two administrations of the ATQ for level of black tea polyphenols and total flavonoids were both 0.77, which fall within the typical range. Few studies have examined reproducibility of intake for specific food items using the food frequency questionnaires, and when done, the reproducibility was generally more variable, ranging from 0.4 to 0.7 (23). For this questionnaire, the correlation for black tea consumption was 0.68 between the two administrations of ATQ.

A major problem in investigating the relationship between tea and cancer is the lack of quantitative data. Black tea is the major form of tea consumed, but its chemistry, biological activities, and chemopreventive properties are not well defined. Most of the studies on tea polyphenols have been conducted to monitor the metabolism of pharmacological doses and not at the levels commonly observed in usual tea beverages. Although plasma samples were available for all of our subjects, we have not attempted to validate the intake of dietary black tea polyphenols in relation to the plasma levels. Tea flavonoids have a relatively short half-life in human plasma (24), and detection requires regular black tea consumption of at least two cups/day. Furthermore, van het Hof *et al.* (25) reported that although plasma levels of flavonoids increased during repeated tea consumption (10 cups/day), they decreased significantly during the nights when no tea was consumed. As such, levels of plasma flavonoids are not suitable biomarkers to evaluate normal patterns of black tea consumption. Similarly, urinary levels of EGC and EC might not be suitable to evaluate normal patterns of black tea consumption. Over 90% of the total urinary EGC and EC is excreted within 6–8 h. Detection of EGC and EC in urine requires collection of 24-h urine from subjects who regularly consume at least one cup of tea/day. In contrast to EGC and EC, EGCG is mainly excreted through the bile and is not detected in urine (25).

The particular limitations and strengths of our study must be considered. The major limitation of the black tea polyphenol database is that it is not complete. We calculated our dietary intake on the basis of 40 different black tea samples. However, biological composition of tea leaves depends not only on preparation techniques but also on other environmental factors, including climate, season, horticultural practices, and the type and age of the plant.

To our knowledge, this is the first study to assess the accuracy and reproducibility of a dietary method to specifically estimate the intake of black tea polyphenols. Thus, direct comparisons of our results to other studies are not possible. Collecting information on the type, preparation, and strength of the consumed tea, as designed in the ATQ, should provide a better tool for collecting dietary information on tea consumption in different populations.

Tea polyphenols intake may vary not only because actual amount of consumption differs but also because the concentrations of tea polyphenols differ by type of tea preparation (13). Estimation of total amount of tea intake in epidemiological studies should include information on the type, preparation, and strength of the consumed tea. Estimates of tea consumption and tea total flavonoids, catechins, theaflavins, thearubigens, gallic acid and caffeine intake were highly reproducible when the questionnaire was administered at two points in time. These data provide additional evidence that a simple, self-administered, semiquantitative tea frequency questionnaire can provide useful information on tea and intake of tea polyphenols.

Appendix

Arizona Tea Questionnaire

ID NUMBER ☐☐☐☐☐☐ - ☐☐

DIRECTIONS

- **Use a BLUE or BLACK ballpoint pen**
- **Make no stray marks**
- **Fill in the circles completely**

Please shade bubbles like this: ●
and *not* like this: ⊗ ✓

Part 1: Demographics

PLEASE PRINT YOUR NAME, TODAY'S DATE, PHONE NUMBER, AGE, AND SEX IN THE BOXES PROVIDED.

1. Name: ☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐

2. Today's Date: ☐☐ - ☐☐ - ☐☐☐☐ (MO - DAY - YR)

3. Phone Number: (☐☐☐) ☐☐☐ - ☐☐☐☐

4. Age: ☐☐ years old

5. Sex ○ Male ○ Female

6a. Which of the following responses best describes your tea use or consumption in the past year (Include hot, iced, and herbal teas)?

- ○ Frequent or regular tea drinker
- ○ Occasional tea drinker
- ○ Herbal tea drinker only
- ○ Never drink tea

IF YOU CURRENTLY DO NOT DRINK TEA:

6b. Did you used to drink tea?

○ Yes ***-Go to Question 18 (Page 6)*** ○ No ***-STOP***

OFFICE USE ONLY

R N/A M ○ ○ ○

R N/A M ○ ○ ○

R N/A M ○ ○ ○

OFFICE USE ONLY:

Interview Method:
- ○ Office visit
- ○ Phone
- ○ Mail
- ○ Other

Admin. by:
- ○ Tech ..... Admin. by: ____ Init.
- ○ Self
- ○ Guardian
- ○ Other

Form Status: ☐☐

Study: ☐☐ **Stage:** ☐☐ **Collapsed?** Y ○ N ○ 8 ○

Form Status: ☐☐

QC: ____ Init. Tech. ID ☐☐ MO ☐☐ / DAY ☐☐ / YR ☐☐

QA: ____ Init. ☐☐ ☐☐ / ☐☐ / ☐☐

DE: ____ Init. Tech. ID ☐☐ MO ☐☐ / DAY ☐☐ / YR ☐☐

DP Batch: ☐☐☐ QXV: Q T E A 1

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Part 2: For the following questions answer for your USUAL type of HOT tea.

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Arizona Tea Qx

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7a. Do you drink **HOT** tea?

○ Yes *-Continue* ○ No *-Go to Question 8a (Next Page)*

R N/A M ○ ○ ○

IF YES:

7b. How much of the **HOT** tea you drink is decaffeinated?

○ None ○ 25% ○ 50% ○ 75% ○ All

R N/A M ○ ○ ○

7c. How do you usually drink your **HOT** tea?

○ Weak ○ Medium ○ Strong ○ Very Strong

R N/A M ○ ○ ○

7d. At what temperature do you usually drink your **HOT** tea?

○ Room Temperature ○ Warm ○ Hot ○ Very Hot

R N/A M ○ ○ ○

7e. At what time of day do you usually drink your **HOT** tea?

○ Throughout the day ○ With meals only ○ Between meals only

R N/A M ○ ○ ○

7f. How do you usually prepare your **HOT** tea?

○ Recipe *-Continue*

○ Restaurant ○ Bottled only ○ Don't know *-Go to Next Page*

R N/A M ○ ○ ○

If RECIPE:

7g. When making **HOT** tea how much do you use?

☐☐ bags per cup **OR** ☐☐ teaspoons per cup

7h. How long do you brew your **HOT** tea?

☐☐ minutes

7i. Do you usually add anything to your tea?

○ Yes ○ Sometimes *-Continue*

○ Never *-Go to Next Page*

R N/A M ○ ○ ○

If you add anything to your tea:

7j. What do you add to your **HOT** tea?

○ Citrus
○ Spices
○ Sugars/sweeteners
○ Herbs or herbal tea
○ Milk

R N/A M ○ ○ ○

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ID:

Part 3: For the following questions answer for your USUAL type of ICED tea.

OFFICE USE ONLY

R N/A M

8a. Do you drink **ICED** tea?

○ Yes *-Continue* ○ No *-Go to Question 9 (Next Page)*

IF YES:

8b. How much of the **ICED** tea you drink is decaffeinated?

○ None ○ 25% ○ 50% ○ 75% ○ All

8c. How do you usually drink your **ICED** tea?

○ Weak ○ Medium ○ Strong ○ Very Strong

8d. Do you usually add ice to your **ICED** tea before drinking?

○ Yes ○ Sometimes ○ Never

8e. How much of your **BLACK ICED** tea is usually sun tea?

○ None ○ 25% ○ 50% ○ 75% ○ All

8f. How much of your **GREEN ICED** tea is usually sun tea?

○ None ○ 25% ○ 50% ○ 75% ○ All

8g. How long do you keep it refrigerated? ☐☐ days

8h. At what time of day do you usually drink your **ICED** tea?

○ Throughout the day ○ With meals only ○ Between meals only

8i. How do you usually prepare your **ICED** tea?

○ Recipe *-Continue*

○ Restaurant ○ Bottled only ○ Don't know *-Go to Next Page*

If RECIPE:

8j. When making **ICED** tea how much do you use?

☐☐ tea bags or teaspoons per 1/2 gallon pot

8k. How long do you brew your **ICED** tea?

☐☐ minutes **OR** ☐☐ hours

8l. Do you usually add anything to your tea?

○ Yes ○ Sometimes *-Continue*

○ Never *-Go to Next Page*

If you add anything to your tea:

8m. What do you add to your **ICED** tea?

○ Citrus ○ Herbs or herbal tea

○ Spices ○ Milk

○ Sugars/sweeteners

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Part 4: The next questions ask about your use of various types of tea during the past year.

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Arizona Tea Qx

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9. How often do you usually drink the following teas **IN THE SUMMER**? *Please fill in a response for each type of tea.*

	Never/ rarely	Less than 1 cup/ month	1-3 cups per month	1 cup per week	2-3 cups per week	4-6 cups per week	1-2 cups per day	3+ cups per day	R	N/A	M
HOT Black Tea	○	○	○	○	○	○	○	○	○	○	○
ICED Black Tea	○	○	○	○	○	○	○	○	○	○	○
HOT Green Tea	○	○	○	○	○	○	○	○	○	○	○
ICED Green Tea	○	○	○	○	○	○	○	○	○	○	○
HOT Herbal Tea	○	○	○	○	○	○	○	○	○	○	○
ICED Herbal Tea	○	○	○	○	○	○	○	○	○	○	○

10. How often do you usually drink the following teas **IN THE WINTER**? *Please fill in the correct answer for each type of tea.*

	Never/ rarely	Less than 1 cup/ month	1-3 cups per month	1 cup per week	2-3 cups per week	4-6 cups per week	1-2 cups per day	3+ cups per day	R	N/A	M
HOT Black Tea	○	○	○	○	○	○	○	○	○	○	○
ICED Black Tea	○	○	○	○	○	○	○	○	○	○	○
HOT Green Tea	○	○	○	○	○	○	○	○	○	○	○
ICED Green Tea	○	○	○	○	○	○	○	○	○	○	○
HOT Herbal Tea	○	○	○	○	○	○	○	○	○	○	○
ICED Herbal Tea	○	○	○	○	○	○	○	○	○	○	○

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ID:

OFFICE USE ONLY

R N/A M

11. When you drink tea, how much do you usually drink? *Please fill in the correct answer for each type of tea.*

	None	Teacup (7 oz.)	Mug (9 oz.)	Large Mug (11 oz.)	Glass (12 oz.)	Large Glass (16 oz.)
HOT Black Tea	○	○	○	○	○	○
ICED Black Tea	○	○	○	○	○	○
HOT Green Tea	○	○	○	○	○	○
ICED Green Tea	○	○	○	○	○	○
HOT Herbal Tea	○	○	○	○	○	○
ICED Herbal Tea	○	○	○	○	○	○

12. Of the tea you drink what percentage is from BAGS, LOOSE, INSTANT **and** BOTTLED/CANNED? *If 0%, leave the box blank.*

	Bags	Loose	Instant	Bottled/ Canned
HOT Black Tea	☐☐☐ %	☐☐☐ %	☐☐☐ %	☐☐☐ %
ICED Black Tea	☐☐☐ %	☐☐☐ %	☐☐☐ %	☐☐☐ %
HOT Green Tea	☐☐☐ %	☐☐☐ %	☐☐☐ %	☐☐☐ %
ICED Green Tea	☐☐☐ %	☐☐☐ %	☐☐☐ %	☐☐☐ %
HOT Herbal Tea	☐☐☐ %	☐☐☐ %	☐☐☐ %	☐☐☐ %
ICED Herbal Tea	☐☐☐ %	☐☐☐ %	☐☐☐ %	☐☐☐ %

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Part 5: The following questions are about your LIFETIME CONSUMPTION of tea.

Page 6
Arizona Tea Qx

OFFICE USE ONLY

13. For how many **years** have you been drinking tea?

☐☐ years

14. How many **years** did you drink tea before you were **age 25**?

☐☐ years

15. On average, how many **cups** of tea did you usually drink per month at this young age?

☐☐ cups per month

Brand Code: ☐☐☐

16. What **brand** do you usually use? _____

17. Is the pattern you have described for the past year similar to this lifetime pattern?

R N/A M
○ ○ ○

○ Yes
○ No - ***Describe Changes:*** _____

Change Code: ☐☐☐

THANK YOU FOR YOUR TIME. STOP HERE.

The following questions are for those who are currently non-tea drinkers.

18. How many **years** did you drink tea before stopping?

☐☐ years

19. How many **years** did you drink tea before you were **age 25**?

☐☐ years

20. When you were drinking tea, how many **cups** of tea did you usually drink **per month?**

☐☐ cups per month

21. What **type of tea** were you usually drinking?

R N/A M
○ ○ ○

○ Black ○ Green ○ Herbal ○ Mix

22. Why did you quit?

R N/A M
○ ○ ○

○ Health problems
○ Didn't like taste
○ Other (Specify: _____)

Change Code: ☐☐☐

THANK YOU FOR YOUR TIME. STOP HERE.

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References

1. Zheng, W., Doyle, T. G., Kushi, L. H., Sellers, T. S., Hong, C-P., and Folsom, A. R. Tea consumption and cancer incidence in a prospective cohort study of postmenopausal women. Am. J. Epidemiol., *144:* 175–182, 1996.

2. Inoue, M., Tajima, K., Hirose, K., Hamajima, N., Takezaki, T., Kuroishi, T., and Tominaga, S. Tea and coffee consumption and the risk of digestive tract cancers: data from a comparative case-referent study in Japan. Cancer Causes Control, *9:* 209–216, 1998.

3. Li, N., Sun, X., Han, C., and Chen, J. The chemoprevention effects of tea on human oral precancerous mucosa lesions. Proc. Soc. Exp. Biol. Med., *220:* 218–224, 1999.

4. Sesso, H. D., Gaziano, J. M., Buring, J. E., and Hennekens, C. H. Coffee and tea intake and the risk of myocardial infarction. Am. J. Epidemiol., *149:* 162–167, 1999.

5. Keli, S. O., Hertog, M. G. L., Feskens, E. J. M., and Kromhout, D. Dietary flavonoids, antioxidant vitamins, and incidence of stroke. Arch. Intern. Med., *154:* 637–642, 1996.

6. Hertog, G. L. M., Feskens, E. J. M., Hollman, P. C. H., Katan, M. B., and Kromhout, D. Dietary antioxidant flavonoids and risk of coronary heart disease: the Zutphen Elderly Study. Lancet, *342:* 1007–1011, 1993.

7. Johnell, O., Gullberg, B., Kanis, J. A., Allander, E., Elffors, L., Dequeker, J., Filsen, G., Gennari, C., Lopes Va, A., and Lyritis, G. Risk factors for hip fracture in European women: the MEDOS study (Mediterranean Osteoporosis Study). J. Bone Miner. Res., *10:* 1802–1815, 1995.

8. Hegarty, V. M., May, H. M. and Khaw, K-T. Tea drinking and bone mineral density in older women. Am. J. Clin. Nutr., *71:* 1003–1007, 2000.

9. Kao, P. C., and Peng, F. K. How to reduce the risk factors of osteoporosis in Asia. Chin. Med. J., *55:* 209–213, 1995.

10. Ivor, E., and Dreosti, I. E. Cancer biomarkers in the field of tea. Cancer Lett., *114:* 319–321, 1997.

11. Graham, H. N. Green tea composition, consumption and polyphenol chemistry. Prev. Med., *21:* 334–350, 1992.

12. Paganga, G., Miller, N., and Rice-Evans, C. A. The polyphenolic content of fruit and vegetables and their antioxidant activities. What does a serving constitute? Free Radical Res., *30:* 153–162, 1999.

13. Hakim, I. A., Weisgerber, U. M. Harris, R. B. Balentine, D. van-Mierlo, C. A. J., and Paetau-Robinson, I. Preparation, Composition and Consumption Patterns of Tea-based Beverages in Arizona. Nutri. Res., *20:* 1715–1724, 2000.

14. Hakim, I. A., Harris, R. B., and Weisgerber, U. Tea intake and skin squamous cell carcinoma: influence of type of tea beverages. Cancer Epidemiol. Biomark. Prev., *9:* 727–731, 2000.

15. SAS/STAT, release 6.12. Carey, NC: SAS Institute, 1996.

16. Block, G., Hartmann, A. M., Dresser, C. M., Carroll, M. D., Gannon, J., and Gardner, L. A. A data based approach to diet questionnaire design and testing. J. Am. Diet Assoc., *124:* 453–469, 1986.

17. Stata Corp. Stata Statistical Software, Intercooled Stata, release 6.0. College Station, TX: Stata Corp., 1999.

18. Willett, W. C., Reynolds, R. D., Cottrell-Hoehner, S., Sampson, L., and Browne, M. L. Validation of a semi-quantitative food frequency questionnaire: comparison with a 1-year diet record. J. Am. Diet Assoc., *87:* 43–47, 1987.

19. Rimm, E. B., Giovannucci, E. L., Stampfer, M. J., Colditz, G. A., Litin, L. B., and Willet, W. C. Authors' response to "Invited commentary; some limitations of semi quantitative food frequency questionnaires." Am. J. Epidemiol., *135:* 1133–1136, 1992.

20. Willett, W. C., Sampson, L., Stampfer, M. J., Rosner, B., Bain, C., Witschi, J., Hennekens, C. H., and Speizer, F. E. Reproducibility and validity of a semi quantitative food frequency questionnaire. Am. J. Epidemiol., *122:* 51–65, 1985.

21. Block, G., Woods, M., Potosky, A., and Clifford, C. Validation of a self-administered diet history questionnaire using multiple diet records. J. Clin. Epidemiol., *43:* 1327–1335, 1990.

22. Munger, R. G., Folson, A. R., Kushi, L. H., Kaye, S. A., and Sellers, T. A. Dietary assessment of older Iowa women with a food frequency questionnaire: nutrient intake, reproducibility, and comparison with 24-hour dietary recall interviews. Am. J. Epidemiol., *136:* 192–200, 1992.

23. Zulkifli, S. N., and Yu, S. M. The food frequency method for dietary assessment. J. Am. Diet Assoc., *92:* 681–685, 1992.

24. Hollman, P. C. H., Tijburg, L. B. M., and Yang, Y. S. Bioavailability of flavonoids from tea. Crit. Rev. Food Sci. Nutr., *37:* 719–738, 1997.

25. van het Hof, Wiseman, S. A., Yang, C. S., and Tijburg, L. B. M. Plasma and lipoprotein levels of tea catechins following repeated tea consumption. Proc. Soc. Exp. Biol. Med., *220:* 203–209, 1999.

Reproducibility and Relative Validity of a Questionnaire to Assess Intake of Black Tea Polyphenols in Epidemiological Studies

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