Research Square

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Effect of a School-Based Salt Reduction Health Education Program on Urinary Sodium, Potassium, and KAP Among Primary School Students and Their Parents: A Quasi-Experimental Study

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Abstract

Background

Excessive sodium intake in childhood is a key modifiable risk factor for cardiovascular disease, yet school-based salt reduction programs targeting the school food environment have not been evaluated in eastern China.

Methods

We conducted a quasi-experimental cluster-controlled trial in 20 primary schools across two cities in Jiangsu Province, China. Ten intervention schools received a one-year multi-component program comprising digital health education (WeChat mini-program), classroom activities, school cafeteria sodium reduction, and campus health promotion; ten control schools received routine health education. Outcomes were assessed in 487 student–parent pairs at baseline and follow-up, including 24-hour urinary sodium, potassium, Na/K ratio, and salt-related knowledge, attitudes, and practices (KAP). Intervention effects were estimated using linear mixed models under an intention-to-treat framework.

Results

KAP scores improved significantly in both students (net difference 16.55, $P < 0.001$) and parents (net difference 4.60, $P < 0.001$). Parent 24-hour NaCl excretion decreased by 0.63 g/day (95% *CI*: −1.11, − 0.14; $P = 0.012$). Student 24-hour potassium excretion increased by 0.17 g/day (95% *CI*: 0.10, 0.25; $P < 0.001$), while student sodium excretion did not change significantly. Cafeteria sodium content fell by 38% in intervention schools at follow-up, significantly lower than in control schools ($P < 0.001$). Among intervention-group students, greater school lunch attendance was associated with larger reductions in urinary sodium and Na/K ratio, though interaction terms did not reach conventional significance.

Conclusions

This multi-component school-based intervention improved KAP, reduced parental sodium intake, increased children's potassium excretion, and objectively modified the school food environment, but did not reduce children's overall sodium excretion. School-based strategies may need to be combined with direct engagement of household meal preparers to achieve meaningful reductions in children's dietary sodium.

Introduction

Noncommunicable diseases remain the leading cause of death globally, with cardiovascular disease accounting for approximately one-third of all mortality[1]. Elevated blood pressure is the single largest modifiable risk factor, contributing to an estimated 10.8 million deaths annually. In China, the age-standardized prevalence of hypertension among adults reached 27.5% by 2018, affecting over 300 million people, and the burden of stroke and ischemic heart disease is rising most rapidly in eastern provinces[2]. Critically, the roots of this epidemic extend into childhood: elevated blood pressure in childhood tracks into adulthood, and the prevalence of elevated blood pressure among Chinese school-aged children has risen in parallel with childhood overweight and obesity. Population-level salt reduction is among the most cost-effective strategies for cardiovascular prevention; modeling studies project that even modest reductions in population sodium intake could avert millions of cardiovascular events in China over the coming decade[3, 4]. These converging lines of evidence underscore the importance of initiating preventive interventions early in the life course.

Despite decades of public health efforts, mean global sodium intake remains more than double the WHO recommendation of < 2.0 g sodium/d (< 5 g salt/d), while mean potassium intake is less than half the recommended 3.5 g/d[5, 6]. In China, household cooking salt consumption has declined modestly over the past decade, yet total sodium intake remains substantially above target, driven increasingly by processed foods, soy sauce, and out-of-home meals[7, 8]. This excess begins early: among Chinese children aged 6–17 years, median salt intake was 6.1 g/d in 2016–2017, with 67.8% exceeding age-specific recommendations[9]. Physiologically, sodium and potassium are independently and jointly associated with blood pressure and cardiovascular outcomes[10, 11]. Prospective studies using 24-hour urine collections have demonstrated graded, dose-response associations between higher sodium excretion, lower potassium excretion, and increased cardiovascular risk[12, 13]. The urinary sodium-to-potassium (Na/K) ratio, which integrates both exposures into a single index, has been shown to outperform either electrolyte alone in predicting cardiovascular events[10, 13]. Sustained sodium reduction produces durable clinical benefit, as confirmed by long-term follow-up of randomized trials[14–16].

Accurately evaluating these vital cardiovascular metrics, however, presents a distinct challenge in the Chinese context. Approximately 70–80% of dietary sodium in China comes from salt and high-sodium condiments added during home cooking[8], making the household food environment the dominant modifiable determinant of sodium intake for both children and adults. Given the predominance of discretionary salt use and the limitations of dietary recall methods in capturing sodium from condiments and sauces, objective measurement is paramount. Twenty-four-hour urinary excretion, the gold standard method recommended by the WHO, captures sodium from all dietary sources and avoids the systematic measurement error inherent in self-reported dietary assessment[17]. Together, 24-hour urinary sodium, potassium, and the Na/K ratio represent robust biomarkers for evaluating the physiological impact of salt reduction interventions.

School-based interventions are uniquely positioned to combine behavioral education with modifications of the food environment, thereby reaching both individual dietary choices and the contexts in which those choices are made. The landmark School-EduSalt trial in northern China first demonstrated that a school-based education program reduced salt intake by 1.9 g/d in children and 2.9 g/d in adults[18]. The subsequent AppSalt trial—a multi-city cluster-randomized trial incorporating a smartphone application—extended these findings, showing reductions in adult salt intake and systolic blood pressure at 12 months, with KAP improvements sustained at 24 months[19, 20].

Several important gaps remain in the current literature. First, landmark trials like School-EduSalt and AppSalt relied exclusively on educational components delivered to students and families[19–21]. Whether simultaneously modifying the school food environment can enhance the effectiveness of school-based salt reduction programs remains untested in a Chinese primary school setting. Furthermore, the fidelity of such environmental interventions has never been objectively quantified, such as through direct measurement of cafeteria sodium content. Second, existing trials were conducted predominantly in northern China; their findings may not generalize to eastern provinces where soybean-based condiments drive a different dietary sodium profile[22]. Finally, while cross-sectional data show moderate parent–child dietary concordance[23], it remains unknown whether a child-oriented school intervention can alter these shared household dietary patterns.

To address these gaps, we conducted a quasi-experimental controlled trial in 20 primary schools across two cities in eastern China. This study aimed to explore whether a multi-component intervention—integrating behavioral education with objective school cafeteria sodium reduction—could effectively improve salt-related KAP, optimize 24-hour urinary sodium and potassium excretion, and lower the Na/K ratio among grade 3 students and their parents, relative to routine school health education.

Methods

2.1 Study Design and Participants

This quasi-experimental cluster-controlled trial was conducted in 20 primary schools across Zhenjiang (intervention) and Yangzhou (control), Jiangsu Province, China. Schools were selected using probability-proportional-to-size sampling: six urban and four rural schools were randomly drawn from each city, yielding 10 schools per city. Within each school, one third-grade class was randomly selected, and approximately 25 students per class were randomly sampled, with efforts to maintain sex balance. Each enrolled student was required to recruit one parent or guardian for paired assessment. The target enrollment was 496 student–parent pairs. Baseline assessments were completed in June 2022, and the intervention spanned one full academic year (September 2022 to June 2023), with follow-up assessments conducted in June 2023. The primary efficacy analyses were prespecified to follow the intention-to-treat (ITT) principle, complemented by a per-protocol (PP) analysis.

2.2 Inclusion and Exclusion Criteria

Inclusion criteria were: (1) no planned school transfer during the 12-month study period; (2) the enrolled parent was the primary meal preparer or, alternatively, the primary learning supervisor in the household; (3) parent age 18–75 years; and (4) absence of severe hepatic, renal, or gastrointestinal disease, or diabetic complications. Exclusion criteria were: (1) refusal or inability to collect 24-hour urine; (2) pregnancy, planned pregnancy, or lactation; and (3) inability to comply with study requirements.

2.3 Intervention

Control-group schools continued their standard health education curriculum without additional input from the research team. The intervention group received a multi-component salt reduction health education program comprising four elements:

(1) Online Health Education. A WeChat mini-program ("Healthy Salt Cloud Classroom"), developed in collaboration with the China Health Education Center and the George Institute for Global Health, delivered video-based lessons to students and parents. The curriculum included eight lessons on salt reduction and twelve on healthy lifestyles, each approximately five minutes in duration. One lesson was released weekly; students and parents studied together and completed post-lesson quizzes and practical tasks, earning points toward rewards.

(2) Offline Classroom Activities. Schools were provided with health education animation videos, posters, and printed materials. Teachers delivered one themed health education session per week, and each school organized one health-themed competition per semester.

(3) School Cafeteria Intervention. Cafeteria staff received salt reduction education and practical training covering kitchen salt-usage monitoring, awareness of high-salt risks, and cooking techniques for salt reduction.

(4) Campus Health Environment. Salt reduction posters were displayed in cafeterias, classrooms, and common areas; promotional videos and radio broadcasts were aired regularly on campus media platforms.

2.4 Data Collection and Outcome Measures

2.4.1 Questionnaires and KAP Assessment

Structured questionnaires were administered to assess demographic characteristics, health-related behaviors, and salt-related knowledge, attitudes, and practices (KAP). All questionnaires were completed at baseline and follow-up under the supervision of trained investigators.

2.4.2 24-Hour Urine Collection

At each time point, participants provided one 24-hour urine sample. Trained investigators distributed collection containers with detailed instructions. Participants discarded the first morning void, then collected all urine over the subsequent 24 hours (± 2 hours), returning the container the following morning. Total urine volume was recorded to the nearest mL. Samples with collection time deviations, mid-collection spillage, or volume below age-appropriate thresholds (< 250 mL for children, < 500 mL for adults) were discarded and recollected when feasible. Urinary sodium, potassium, and creatinine concentrations were measured at the Guangzhou KingMed Diagnostics Center using an electrolyte analyzer (sodium and potassium) and spectrophotometry (creatinine). Salt intake was estimated as salt (g/day) = sodium (g/day) × 2.54. Samples with creatinine below sex-specific thresholds (< 4.0 mmol/day for adult females, < 6.0 mmol/day for adult males, < 2.5 mmol/day for girls, and < 2.9 mmol/day for boys) were excluded from urinary biomarker analyses[24, 25].

2.4.3 Blood Pressure

Blood pressure was measured three times at each assessment using a validated automated oscillometric device, following a standardized protocol. The mean of the second and third readings was used for analysis.

2.4.4 School Lunch Samples

School cafeteria lunches were collected from ten intervention and ten control schools (one week of meals per school per time point; n = 50 meals per group per time point) for sodium, potassium, and salt content analysis via inductively coupled plasma mass spectrometry (ICP-MS).

2.5 Statistical Analysis

Continuous variables were summarized as mean ± standard deviation for normally distributed data and as median (interquartile range) otherwise; normality was assessed using the Shapiro–Wilk test. Categorical variables were presented as frequencies and percentages. Baseline between-group comparisons used independent t-tests (or Welch t-tests for unequal variances) for normally distributed continuous variables, Mann–Whitney U tests for non-normal continuous variables, and chi-square or Fisher exact tests for categorical variables. The primary analysis followed the intention-to-treat (ITT) principle. Missing outcome data were handled using multiple imputation by chained equations (MICE) with five imputed datasets, implemented via the Iterative Imputer (scikit-learn) with Bayesian ridge regression, 30 maximum iterations, and posterior sampling. Estimates were pooled across imputations using Rubin's rules[26].

Intervention main effects on KAP and continuous urinary outcomes were estimated using linear mixed-effects models (LMM). The models included treatment group, time, and their interaction (group × time) as fixed effects, and family ID as a random effect to account for household-level clustering. To further control for confounding, these models were adjusted for age, sex, and all variables that exhibited significant between-group differences at baseline.

For intergenerational predictive modeling and moderation analyses, multivariable linear regression models were employed, incorporating school-level fixed effects and cluster-robust standard errors clustered by school to account for within-school correlation. The dependent variable in these models was the change in biomarkers from baseline to follow-up (Δ). Moderation analyses examined whether intervention effects were modified by in-school lunch frequency and household salt load. In-school lunch frequency was calculated as 7 minus the student's weekly home lunch frequency at follow-up. Household salt load was defined as the parent's baseline 24-h urinary NaCl excretion multiplied by the student's weekly home lunch frequency at follow-up. The moderation models included corresponding two-way interaction terms, adjusting for age, sex, and school-level clustering.

All tests were two-sided with statistical significance set at $P < 0.05$. Analyses were performed using SPSS 27.0.

Results

3.1 Participant Flow and Baseline Characteristics

A total of 510 student-parent pairs were initially recruited for the study. Prior to the completion of baseline assessments and formal enrollment, 23 pairs were excluded due to changes in family structure, guardian non-compliance with the study protocol, or subjective refusal. This resulted in a primary ITT population of 487 pairs. During the one-year follow-up and subsequent data quality control, an additional 46 pairs were excluded from the PP analysis: 39 pairs were excluded due to invalid 24-hour urine samples, and 7 pairs were excluded due to missing follow-up questionnaires. Consequently, the final PP population comprised 441 student-parent pairs (see Fig. 1 for detailed participant flow).

Among students, the two groups were comparable on most demographic and clinical measures, including sex distribution, anthropometric indices (height, weight, BMI), diastolic blood pressure, and all urinary biomarkers (24-h urinary sodium, potassium, and Na/K ratio; all $P > 0.05$). Systolic blood pressure was higher in the control group (100.00 ± 9.89 vs. 96.89 ± 8.76 mmHg, $P < 0.001$). Students in the control group were younger (median 8.0 vs. 8.3 years, $P < 0.001$) and consumed more meals at home (median home lunch frequency 2.0 vs. 2.0 days/week, IQR 2.0–6.0 vs. 2.0–2.0; $P < 0.001$), reflecting underlying demographic differences between the two cities.

Among parents, the groups differed on several sociodemographic and clinical characteristics. Control-group parents were older (median 37.0 vs. 34.9 years, $P < 0.001$), had higher BMI (median 24.8 vs. 24.0 kg/m², $P = 0.014$), higher systolic and diastolic blood pressure (systolic: median 116.7 vs. 110.0 mmHg, $P < 0.001$; diastolic: median 76.3 vs. 73.7 mmHg, $P = 0.002$), and larger household size (median 3 vs. 2 persons, $P < 0.001$). Educational attainment and household income differed significantly between groups ($P < 0.001$ and $P = 0.040$, respectively), with control-group parents having proportionally more high school or above education (23.8% vs. 7.5%) and intervention-group parents reporting higher incomes in the 50k–100k bracket (15.5% vs. 8.5%). Importantly, 24-h urinary sodium and potassium excretion did not differ between groups ($P = 0.840$ and $P = 0.162$, respectively), indicating comparable baseline salt intake. The urinary Na/K ratio was modestly higher in the control group (median 2.78 vs. 2.53, $P = 0.021$).

Baseline characteristics in the PP population (n = 421) were consistent with those of the ITT population (Supplementary Table 1). All between-group differences identified at baseline were adjusted for in subsequent multivariable models

Table 1
Baseline characteristics of students (ITT analysis)

Characteristics	Control(n = 242)	Intervention(n = 245)	*P*
Sex, n (%)			
Male	123 (50.8%)	124 (50.6%)	
Female	119 (49.2%)	121 (49.4%)	1.000
Area, n (%)			
Urban	147 (60.7%)	145 (59.2%)	
Rural	95 (39.3%)	100 (40.8%)	0.796
Age (years)	8.00 (8.00, 8.00)	8.30 (8.10, 8.60)	< 0.001
Height (cm)	132.25 (127.72, 136.00)	132.40 (128.60, 136.40)	0.511
Weight (kg)	27.50 (24.70, 32.88)	27.40 (25.00, 31.90)	0.818
BMI (kg/m2)	15.84 (14.59, 18.28)	15.77 (14.64, 17.60)	0.614
Systolic BP (mmHg)	100.00 ± 9.89	96.89 ± 8.76	< 0.001
Diastolic BP (mmHg)	63.67 (58.67, 67.33)	63.33 (58.33, 68.00)	0.779
24h Urinary Sodium (g/d)	1.80 (1.38, 2.38)	1.86 (1.34, 2.45)	0.915
24h Urinary Potassium (g/d)	0.79 (0.57, 1.08)	0.85 (0.64, 1.13)	0.175
Urinary Na/K ratio	2.27 (1.70, 3.11)	2.18 (1.56, 2.94)	0.225
Total KAP score	50.00 (33.33, 58.33)	41.67 (33.33, 58.33)	0.193
Home lunch (days/week)	2.00 (2.00, 6.00)	2.00 (2.00, 2.00)	< 0.001
Total home meals (times/week)	2.00 (2.00, 6.00)	2.00 (2.00, 2.00)	< 0.001

Note: Data are presented as mean ± SD for normally distributed variables and as median (IQR) for non-normally distributed variables, unless otherwise indicated. Categorical variables are shown as n (%). *P* values were derived from independent-samples t-tests or Welch's t-test for normally distributed continuous variables, Mann–Whitney U tests for non-normal continuous variables, and chi-square or Fisher's exact tests for categorical variables. ITT, intention-to-treat; BMI, body mass index; SBP, systolic blood pressure; DBP, diastolic blood pressure; KAP, knowledge, attitude, and practice.

Table 2
Baseline characteristics of parents (ITT analysis)

Characteristics	Control(n = 242)	Intervention(n = 245)	*P*
Sex, n (%)			
Male	91 (37.6%)	82 (33.5%)	
Female	151 (62.4%)	163 (66.5%)	0.391
Area, n (%)			
Urban	147 (60.7%)	145 (59.2%)	
Rural	95 (39.3%)	100 (40.8%)	0.796
Education, n (%)			
Primary	57 (23.6%)	70 (28.6%)	
Junior high	102 (42.1%)	141 (57.6%)	
High school/vocational	30 (12.4%)	16 (6.5%)	
College degree or higher	53 (21.9%)	18 (7.3%)	< 0.001
Annual household income, n (%)			
<25k	18 (7.4%)	25 (10.2%)	
25k-<50k	194 (80.2%)	166 (67.8%)	
50k-<100k	19 (7.9%)	37 (15.1%)	
100k+	11 (4.5%)	17 (6.9%)	0.016
Age (years)	37.98 (33.00, 53.00)	35.00 (32.80, 40.90)	< 0.001
Height (cm)	161.50 (156.72, 167.47)	161.50 (157.50, 169.00)	0.223
Weight (kg)	65.23 (56.95, 72.47)	62.50 (54.70, 71.80)	0.081
BMI (kg/m2)	24.03 (21.94, 27.41)	23.51 (21.24, 26.09)	0.059
Systolic BP (mmHg)	117.33 (107.25, 129.25)	110.33 (102.00, 120.67)	< 0.001
Diastolic BP (mmHg)	76.67 (70.42, 83.92)	73.67 (68.00, 80.00)	< 0.001
Family size (persons)	3.00 (2.00, 4.00)	2.00 (2.00, 3.00)	< 0.001
24h Urinary Sodium (g/d)	3.49 (2.48, 4.29)	3.42 (2.41, 4.30)	0.789
24h Urinary Potassium (g/d)	1.18 (0.91, 1.55)	1.27 (0.94, 1.65)	0.142
Urinary Na/K ratio	2.65 (1.85, 3.59)	2.42 (1.73, 3.30)	0.096
Total KAP score	53.33 (46.67, 66.67)	60.00 (46.67, 73.33)	0.010

Note: Data are presented as mean ± SD for normally distributed variables and as median (P25, P75) for non-normally distributed variables, unless otherwise indicated. Categorical variables are shown as n (%). Percentages were calculated based on respondents with available data. *P* values were derived from independent-samples t-tests or Welch's t-test for normally distributed continuous variables, Mann–Whitney U tests for non-normal continuous variables, and chi-square or Fisher's exact tests for categorical variables. ITT, intention-to-treat; BMI, body mass index; SBP, systolic blood pressure; DBP, diastolic blood pressure; KAP, knowledge, attitude, and practice.

3.2 Intervention Effects on KAP, Urinary Biomarkers, and Home Meal Frequency

Table 3 presents the net effects of the family-based intervention on behavioral and physiological outcomes. Regarding behavioral changes, total KAP scores increased significantly for both students (*ND*: 16.55, 95% *CI*: 9.38, 23.72; $P < 0.001$) and parents (*ND*: 4.60, 95% *CI*: 3.74, 5.47; $P < 0.001$). Specifically, students showed improvements in knowledge and attitude ($P < 0.001$) alongside a decrease in practice scores (*ND*: -5.74, $P = 0.035$). Parents exhibited increased knowledge ($P < 0.001$) and a slight decrease in attitude (*ND*: -3.58, $P = 0.001$), with unchanged practice scores.

For objective biomarkers, parent 24-hour NaCl excretion significantly decreased by 0.63 g/day (*ND*: -0.63, 95% *CI*: -1.11, -0.14; $P = 0.012$), accompanied by a borderline significant reduction in 24-hour Na ($P = 0.055$). Concurrently, student 24-hour K excretion significantly increased (*ND*: 0.17 g/day, 95% *CI*: 0.10, 0.25; $P < 0.001$), while their sodium-related metrics showed no significant changes.

Additionally, students' weekly home lunch frequency decreased significantly (*ND*: -0.35 sessions/week, 95% *CI*: -0.63, -0.06; $P = 0.017$), whereas the total weekly home meals showed no significant difference ($P = 0.123$).

3.3 School Cafeteria Lunch Sodium Content

Sodium, salt, and potassium content of school cafeteria lunches were analyzed in a subset of 10 schools per group. At baseline, sodium content did not differ significantly between control and intervention school lunches (1.13 ± 0.26 g vs. 1.05 ± 0.31 g per meal, $P = 0.171$). At follow-up, intervention school lunches had significantly lower sodium content (0.65 ± 0.19 g vs. 0.87 ± 0.25 g, $P < 0.001$) and salt content (1.66 ± 0.47 g vs. 2.20 ± 0.63 g, $P < 0.001$). The pre-post change in sodium content trended toward greater reduction in intervention schools (− 0.40 ± 0.16 g vs. −0.26 ± 0.13 g, $P = 0.06$), and the reduction in potassium content was significantly larger in intervention schools (− 0.12 ± 0.10 g vs. −0.02 ± 0.05 g, $P = 0.01$).

3.4 Intra-Individual Correlations Among Urinary Biomarkers

Cross-pair Pearson correlations between matched students and parents were examined to evaluate intra-household dietary concordance (Supplementary Table 4). At baseline, positive correlations were observed for most urinary biomarkers in both groups. At follow-up, the cross-pair correlation coefficients within the control group decreased for sodium ($\Delta r = -0.206$, $P = 0.048$), potassium ($\Delta r = -0.209$, $P = 0.038$), and creatinine ($\Delta r = -0.256$, $P = 0.015$). In contrast, the correlation coefficients within the intervention group showed no significant changes from baseline to follow-up (all P for $\Delta r > 0.10$). Between-group comparisons of Δr revealed a significant difference only for creatinine ($P = 0.016$).

Multivariable linear regression models, adjusted for student age, sex, and school-level clustering, revealed significant intergenerational predictive effects (Table 5). At baseline, parental biomarkers in the intervention group significantly predicted corresponding student outcomes for sodium ($B = 0.110$, $P = 0.006$), potassium ($B = 0.151$, $P = 0.003$), and the Na/K ratio ($B = 0.290$, $P < 0.001$). Similarly, all four parental biomarkers—sodium, potassium, Na/K ratio, and creatinine—in the control group demonstrated significant predictive effects on student metrics (all $P < 0.05$). During the follow-up period, these significant predictive effects persisted for parental potassium ($B = 0.156$, $P = 0.005$) and the Na/K ratio ($B = 0.179$, $P = 0.005$) in the intervention group, as well as for parental potassium ($B = 0.071$, $P = 0.010$) in the control group. No significant three-way interaction effects were observed across the biomarkers.

3.5 Moderation of Intervention Effects by School and Home Food Environments

Multiple linear regression models examined whether the intervention effect on changes in 24-hour urinary biomarkers was moderated by in-school lunch frequency and household salt load (Table 6). For change in 24-hour urinary sodium, in-school lunch frequency showed a borderline negative association in the intervention group (B = − 0.24, SE = 0.14, P = 0.081), indicating that intervention-group students who ate lunch at school more frequently tended to experience greater reductions in urinary sodium. No such association was observed in the control group (B = − 0.004, SE = 0.06, P = 0.972). In the full model, the intervention ×in-school lunch frequency interaction term was P = − 0.21 (B = 0.14, SE = 0.132). For the urinary sodium-to-potassium ratio, a similar pattern emerged: in-school lunch frequency was borderline associated with greater Na/K reductions in the intervention group (B = − 0.47, SE = 0.25, P = 0.059) but not in the control group (B = − 0.03,SE = 0.07, P = 0.652), and the interaction term in the full model was P = − 0.44 (B = 0.24, SE = 0.074). Household salt load did not significantly moderate intervention effects for any urinary outcome (all P > 0.10). Changes in urinary potassium and creatinine were not significantly associated with any predictor in either group.

Table 3
Comprehensive LMM analysis of KAP, urinary electrolytes, and meal frequency (ITT analysis).

Variables	Control group			Intervention group			Intervention Effect	
	Baseline	Follow-up	Change (95% *CI*)	Baseline	Follow-up	Change (95% *CI*)	Net Difference (95% *CI*)	*P* value
Student Total KAP Score	47.3 ± 1.1	52.8 ± 1.1	5.48 (1.28, 9.67)	45.6 ± 1.1	67.8 ± 1.2	22.11 (17.29, 26.93)	16.55 (9.38, 23.72)	< 0.001
Student Knowledge	41.8 ± 1.3	48.5 ± 1.3	6.67 (0.07, 13.27)	41.5 ± 1.3	72.3 ± 1.4	30.85 (24.83, 36.86)	26.23 (15.96, 36.49)	< 0.001
Student Attitude	57.0 ± 3.2	50.8 ± 3.2	-6.20 (-13.45, 1.05)	53.1 ± 3.2	62.4 ± 3.1	9.39 (-2.74, 21.51)	43.72 (30.94, 56.50)	< 0.001
Student Practice	43.7 ± 1.2	48.8 ± 1.3	5.04 (1.37, 8.72)	40.9 ± 1.1	48.9 ± 1.4	8.00 (4.04, 11.96)	-5.74 (-11.08, -0.39)	0.035
Parent Total KAP Score	54.4 ± 1.1	55.3 ± 1.0	0.96 (-2.84, 4.76)	58.0 ± 1.1	67.4 ± 1.0	9.37 (4.53, 14.20)	4.60 (3.74, 5.47)	< 0.001
Parent Knowledge	57.1 ± 1.4	60.2 ± 1.4	3.15 (-3.91, 10.20)	65.1 ± 1.5	84.9 ± 1.2	19.82 (13.67, 25.98)	12.77 (11.39, 14.14)	< 0.001
Parent Attitude	73.4 ± 2.2	72.7 ± 2.3	-0.74 (-12.39, 10.91)	76.1 ± 2.2	75.3 ± 2.1	-0.80 (-11.88, 10.29)	-3.58 (-5.79, -1.37)	0.001
Parent Practice	46.7 ± 1.3	46.2 ± 1.1	-0.51 (-5.87, 4.84)	46.7 ± 1.3	50.0 ± 1.3	3.27 (-2.07, 8.62)	0.01 (-1.26, 1.28)	0.989
Student 24h Na (g/day)	2.0 ± 0.1	2.1 ± 0.1	0.18 (-0.04, 0.40)	2.0 ± 0.1	2.3 ± 0.1	0.29 (0.03, 0.55)	0.16 (-0.13, 0.44)	0.289
Student 24h NaCl (g/day)	5.0 ± 0.1	5.4 ± 0.2	0.45 (-0.11, 1.02)	5.0 ± 0.1	5.7 ± 0.2	0.74 (0.09, 1.40)	0.40 (-0.34, 1.13)	0.290
Student 24h K (g/day)	0.9 ± 0.0	0.9 ± 0.0	0.02 (-0.07, 0.11)	0.9 ± 0.0	0.9 ± 0.0	0.01 (-0.09, 0.10)	0.17 (0.10, 0.25)	< 0.001
Student 24h Cre (mmol/day)	0.5 ± 0.0	0.6 ± 0.0	0.06 (0.01, 0.10)	0.5 ± 0.0	0.6 ± 0.0	0.06 (0.03, 0.09)	-0.00 (-0.06, 0.05)	0.877

Note: Data are expressed as mean ± standard deviation (SD) for baseline and follow-up values. Within-group changes, net differences between groups, and corresponding 95% confidence intervals (CIs) and *P* values were estimated using Linear Mixed-effects Models (LMM). The models included treatment group, time, and their interaction (group × time) as fixed effects, and family ID as a random effect to account for household clustering. Analyses were conducted under the ITT framework. Missing data were handled using Multiple Imputation by Chained Equations (MICE). KAP, Knowledge, Attitude, and Practice; ITT, Intention-to-Treat; LMM, Linear Mixed-effects Model; MICE, Multiple Imputation by Chained Equations; *ND*, Net Difference; *CI*, Confidence Interval; Na, Sodium; K, Potassium; Cre, Creatinine; NaCl, Sodium Chloride.

Variables	Control group			Intervention group			Intervention Effect	
	Baseline	Follow-up	Change (95% *CI*)	Baseline	Follow-up	Change (95% *CI*)	Net Difference (95% *CI*)	*P* value
Student Na/K Ratio	2.6 ± 0.1	2.6 ± 0.1	0.05 (-0.21, 0.31)	2.4 ± 0.1	2.7 ± 0.1	0.29 (-0.09, 0.67)	0.06 (-0.35, 0.47)	0.785
Parent 24h Na (g/day)	3.7 ± 0.2	4.0 ± 0.3	0.24 (-1.53, 2.00)	3.6 ± 0.2	3.5 ± 0.2	-0.10 (-1.17, 0.97)	-0.40 (-0.80, 0.01)	0.055
Parent 24h NaCl (g/day)	10.4 ± 0.8	10.1 ± 0.8	-0.32 (-1.78, 1.14)	8.8 ± 0.5	8.6 ± 0.5	-0.14 (-1.30, 1.01)	-0.63 (-1.11, -0.14)	0.012
Parent 24h K (g/day)	1.5 ± 0.1	1.5 ± 0.1	-0.05 (-0.57, 0.48)	1.4 ± 0.1	1.3 ± 0.1	-0.10 (-0.39, 0.18)	0.08 (-0.04, 0.19)	0.178
Parent 24h Cre (mmol/day)	2.0 ± 0.4	1.9 ± 0.4	-0.14 (-0.92, 0.65)	1.4 ± 0.2	1.3 ± 0.2	-0.07 (-0.76, 0.63)	0.10 (-0.13, 0.33)	0.394
Parent Na/K Ratio	3.7 ± 0.3	3.4 ± 0.2	-0.35 (-1.44, 0.75)	2.9 ± 0.2	3.0 ± 0.2	0.03 (-0.76, 0.82)	-0.06 (-0.26, 0.14)	0.550
Weekly Home Lunch Frequency	3.5 ± 0.1	3.2 ± 0.1	-0.29 (-0.67, 0.09)	2.2 ± 0.1	1.9 ± 0.0	-0.24 (-0.48, 0.00)	-0.35 (-0.63, -0.06)	0.017
Weekly Total Home Meals	16.6 ± 0.2	16.1 ± 0.2	-0.53 (-1.19, 0.14)	15.5 ± 0.1	15.0 ± 0.1	-0.52 (-0.98, -0.05)	-0.49 (-1.10, 0.13)	0.123

Note: Data are expressed as mean ± standard deviation (SD) for baseline and follow-up values. Within-group changes, net differences between groups, and corresponding 95% confidence intervals (CIs) and *P* values were estimated using Linear Mixed-effects Models (LMM). The models included treatment group, time, and their interaction (group × time) as fixed effects, and family ID as a random effect to account for household clustering. Analyses were conducted under the ITT framework. Missing data were handled using Multiple Imputation by Chained Equations (MICE). KAP, Knowledge, Attitude, and Practice; ITT, Intention-to-Treat; LMM, Linear Mixed-effects Model; MICE, Multiple Imputation by Chained Equations; *ND*, Net Difference; *CI*, Confidence Interval; Na, Sodium; K, Potassium; Cre, Creatinine; NaCl, Sodium Chloride.

Table 4
Sodium and potassium content in school lunch samples.

Variables	**Control group**	**Intervention group**	***t***	***P***
Baseline (n = 50)				
Sodium (g)	1.13 ± 0.26	1.05 ± 0.31	1.38	0.171
Salt (g)	2.87 ± 0.67	2.67 ± 0.79	1.38	0.171
Potassium (g)	0.39 ± 0.10	0.47 ± 0.16	-3.007	0.003
Follow-up (n = 50)				
Sodium (g)	0.87 ± 0.25	0.65 ± 0.19	4.845	< 0.001
Salt (g)	2.20 ± 0.63	1.66 ± 0.47	4.845	< 0.001
Potassium (g)	0.37 ± 0.08	0.35 ± 0.08	1.274	0.206
Difference (n = 10)*				
Sodium (g)	-0.26 ± 0.13	-0.40 ± 0.16	2.011	0.06
Salt (g)	-0.67 ± 0.34	-1.01 ± 0.41	2.011	0.06
Potassium (g)	-0.02 ± 0.05	-0.12 ± 0.10	2.89	0.01

Note: The difference represents the change between the 5-day average values of each school before and after the intervention.

Table 5

Multivariable linear regression models examining the predictive effects of parental urinary biomarkers on student outcomes and the moderating role of the intervention (PP analysis).

Outcome	Parameter	Intervention			Control			Interaction		
Sodium (Na)		*B*	*95%CI*	*P*	*B*	*95%CI*	*P*	*B*	*95%CI*	*P*
								0.051	(−0.119, 0.222)	0.556
	Baseline	0.102	(-0.016, 0.220)	0.090	0.150***	(0.082, 0.218)	< 0.001			
	Follow-up	0.077	(-0.036, 0.190)	0.182	0.041	(-0.062, 0.144)	0.437			
	Change (BL→FU)	-0.040	(-0.161, 0.080)	0.513	-0.093	(-0.212, 0.027)	0.128			
Potassium (K)								0.109	(−0.023, 0.241)	0.105
	Baseline	0.144	(-0.003, 0.290)	0.054	0.159**	(0.064, 0.255)	0.001			
	Follow-up	0.172**	(0.061, 0.283)	0.002	0.054	(-0.014, 0.121)	0.120			
	Change (BL→FU)	0.020	(-0.055, 0.095)	0.603	-0.094	(-0.211, 0.024)	0.117			
Na/K ratio								-0.065	(−0.263, 0.132)	0.518
	Baseline	0.277**	(0.098, 0.456)	0.002	0.135*	(0.009, 0.261)	0.036			
	Follow-up	0.186**	(0.055, 0.316)	0.005	0.107*	(0.006, 0.209)	0.038			
	Change (BL→FU)	-0.109	(-0.267, 0.050)	0.179	-0.047	(-0.170, 0.076)	0.455			
Creatinine								0.141	(−0.020, 0.303)	0.086
	Baseline	0.009	(-0.037, 0.055)	0.708	0.117**	(0.034, 0.201)	0.006			
	Follow-up	0.064	(-0.007, 0.135)	0.078	0.023	(-0.061, 0.107)	0.588			
	Change (BL→FU)	0.037	(-0.069, 0.144)	0.493	-0.106	(-0.233, 0.022)	0.104			

Unstandardized regression coefficients (*B*) from linear models: student ~ parent + age + sex + school FE, with cluster-robust *P*. Change tests: parent × time interaction within each group. Three-way interaction: parent × group × time, testing whether the intervention altered the parent-to-student association trajectory. *** $P < 0.001$, ** $P < 0.01$, * $P < 0.05$

Table 6
Multivariate linear regression of changes in 24-h urinary biomarkers (ITT analysis)

Predictor	Intervention			Control			Full model		
	B	*SE*	*P*	*B*	*SE*	*P*	*B*	*SE*	*P*
24-hour urinary sodium (g/day)									
Intercept	0.95	2.38	0.690	1.27	1.64	0.438	0.71	1.28	0.583
In-school lunch frequency (days/week)	-0.24	0.14	0.081	-0.00	0.06	0.972	-0.01	0.06	0.914
Family salt load (g/day)	-0.03	0.02	0.145	-0.01	0.01	0.425	-0.01	0.01	0.413
Age	0.11	0.27	0.691	-0.14	0.19	0.464	-0.04	0.16	0.810
Male sex	-0.18	0.20	0.368	0.16	0.20	0.417	-0.01	0.14	0.968
Intervention group	-	-	-	-	-	-	1.19	0.77	0.123
Intervention x In-school lunch frequency	-	-	-	-	-	-	-0.21	0.14	0.132
Intervention x Family salt load	-	-	-	-	-	-	-0.01	0.02	0.597
24-hour urinary potassium (g/day)									
Intercept	-0.01	0.37	0.970	-0.30	0.73	0.680	-0.09	0.40	0.816
In-school lunch frequency (days/week)	0.06	0.04	0.165	0.00	0.03	0.911	0.00	0.02	0.966
Family salt load (g/day)	0.01	0.01	0.475	-0.00	0.00	0.374	-0.00	0.00	0.345
Age	-0.01	0.05	0.823	0.05	0.08	0.508	0.02	0.05	0.708
Male sex	-0.02	0.09	0.830	0.07	0.07	0.343	0.02	0.06	0.683
Intervention group	-	-	-	-	-	-	-0.21	0.24	0.395
Intervention x In-school lunch frequency	-	-	-	-	-	-	0.06	0.05	0.212
Intervention x Family salt load	-	-	-	-	-	-	0.01	0.01	0.234
24-hour urinary creatinine (mmol/day)									
Intercept	0.09	0.25	0.723	-0.15	0.50	0.758	-0.04	0.27	0.874
In-school lunch frequency (days/week)	0.01	0.04	0.804	0.01	0.02	0.685	0.01	0.02	0.724

Note: *B*, unstandardized regression coefficient; *SE*, cluster-robust standard error (clustered by school). In-school lunch frequency = 7 − student weekly home lunch frequency at follow-up (days/week). Household salt load = parent 24-h urinary NaCl excretion at baseline (g/day) × student weekly home lunch frequency at follow-up (days/week), representing the total household sodium exposure attributable to home-prepared meals. Male sex is coded as 1 (male) versus 0 (female). The full model includes both intervention and control groups with two-way interaction terms (Intervention × In-school lunch frequency, Intervention × Household salt load). Intervention and control group columns present stratified models. All models adjusted for age, sex, and school-level clustering.

Predictor	Intervention			Control			Full model		
	B	*SE*	*P*	*B*	*SE*	*P*	*B*	*SE*	*P*
24-hour urinary sodium (g/day)									
Family salt load (g/day)	0.00	0.00	0.577	-0.00	0.00	0.859	-0.00	0.00	0.834
Age	-0.01	0.04	0.784	0.03	0.06	0.573	0.01	0.03	0.778
Male sex	-0.01	0.02	0.830	0.04	0.03	0.125	0.02	0.02	0.362
Intervention group	-	-	-	-	-	-	-0.06	0.19	0.770
Intervention x In-school lunch frequency	-	-	-	-	-	-	0.00	0.04	0.905
Intervention x Family salt load	-	-	-	-	-	-	0.00	0.01	0.518
Urinary sodium-to-potassium ratio									
Intercept	0.24	3.55	0.946	2.60	1.85	0.160	0.54	1.82	0.767
In-school lunch frequency (days/week)	-0.47	0.25	0.059	-0.03	0.07	0.652	-0.03	0.07	0.709
Family salt load (g/day)	-0.03	0.03	0.188	-0.00	0.01	0.724	-0.00	0.01	0.755
Age	0.30	0.42	0.476	-0.35	0.21	0.094	-0.02	0.24	0.929
Male sex	0.05	0.31	0.866	-0.11	0.24	0.662	-0.01	0.19	0.948
Intervention group	-	-	-	-	-	-	2.39	1.27	0.059
Intervention x In-school lunch frequency	-	-	-	-	-	-	-0.44	0.24	0.074
Intervention x Family salt load	-	-	-	-	-	-	-0.03	0.02	0.204

Note: *B*, unstandardized regression coefficient; *SE*, cluster-robust standard error (clustered by school). In-school lunch frequency = 7 − student weekly home lunch frequency at follow-up (days/week). Household salt load = parent 24-h urinary NaCl excretion at baseline (g/day) × student weekly home lunch frequency at follow-up (days/week), representing the total household sodium exposure attributable to home-prepared meals. Male sex is coded as 1 (male) versus 0 (female). The full model includes both intervention and control groups with two-way interaction terms (Intervention × In-school lunch frequency, Intervention × Household salt load). Intervention and control group columns present stratified models. All models adjusted for age, sex, and school-level clustering.

Discussion

This quasi-experimental trial tested a one-year school-based salt reduction program combining digital learning, classroom education, cafeteria sodium reduction, and campus health promotion in 20 primary schools across two cities in eastern China. KAP improved in both students and parents. Parent 24-hour NaCl excretion fell by 0.63 g/day (P = 0.012). Student 24-hour potassium excretion rose by 0.17 g/day (P < 0.001). Student 24-hour sodium excretion did not move. The pattern tells a coherent story: the intervention changed what happened at school, improved what people knew, and produced biomarker-level effects in parents, but most of children's dietary sodium came from somewhere the program barely touched.

4.1 KAP Improvements

The intervention significantly improved knowledge and attitude scores in both students and parents, yielding gains comparable to prior trials such as School-EduSalt and AppSalt [18, 19]. However, practice scores did not meaningfully change, highlighting a clear knowledge-behavior gap. While education effectively shifted awareness, translating this into reduced sodium intake proved challenging. Changing family cooking habits requires altering routines embedded in culture, budget, and collective household preferences. This barrier is well documented and explains why educational components alone rarely shift physiological biomarkers[27].

This behavioral resistance was compounded by a narrowing environmental contrast in the school setting. Our objective evaluation of school cafeteria meals using ICP-MS, a methodological strength absent from prior Chinese school-based trials, revealed that sodium content fell by approximately 38% in intervention schools. Nevertheless, a parallel, albeit smaller, decline in control schools rendered the between-group difference non-significant ($P = 0.06$). This control-group reduction likely reflects secular trends in public health awareness, national salt reduction policies[28, 29], or partial contamination through shared procurement practices. Consequently, the study effectively compared two partially improved conditions rather than an intervention against a static baseline.Against this backdrop of partial environmental improvement and entrenched household habits, student 24-hour sodium excretion remained unchanged. School lunches account for only roughly five of a child's 21 weekly meals. Modifying a fraction of dietary exposure is unlikely to shift the 24-hour total. This is further complicated by the high day-to-day variability of a single 24-hour urine collection [12, 30]. and the documented reluctance of grandparents, who frequently manage domestic cooking in multi-generational families, to alter traditional methods[20]. Interestingly, while sodium excretion did not change, student 24-hour potassium excretion increased significantly by 0.17 g/day ($P < 0.001$). This divergence suggests that approach-oriented behaviors, such as adding fruits and vegetables, are more readily adopted by children than avoidance-oriented behaviors like restricting salt. Given that Chinese children's potassium intake is well below recommendations[9], this increment offers population-level cardiovascular benefits[12, 31], even if the clinical significance of this specific increment remains uncertain.

The contrast with the adult cohort further clarifies the intervention's mechanism. Parent 24-hour NaCl excretion fell by 0.63 g/day ($P = 0.012$), with a borderline reduction in sodium ($P = 0.055$), comparable to reductions seen in AppSalt adults. Because parents are the primary meal preparers and received direct digital education via the WeChat program, the intervention effectively bypassed the traditional child-to-parent diffusion model[18, 32] and functioned as a successful direct-to-adult intervention[33]. Finally, two subdomain findings from the KAP assessment warrant methodological caution. Student practice scores (net difference − 5.74, $P = 0.035$) and parent attitude scores (net difference − 3.58, $P = 0.001$) declined over the study period. Rather than indicating worsened habits, this may reflect a response shift wherein educated participants evaluated their own behaviors more critically at follow-up. Future trials must account for this phenomenon by examining KAP components separately and maintaining robust objective biomarker tracking.

4.2 Parent-Child Concordance and Moderation Analyses

To examine the underlying mechanisms, we first evaluated household-level dietary concordance and intergenerational predictive modeling. At baseline, robust cross-pair correlations and predictive effects between matched parents and students were observed across both groups, confirming the profound influence of the shared household food environment. This finding is consistent with previous evidence showing significant parent–child resemblance in dietary behaviors and nutrient intakes, reflecting the central role of shared food environments and parental modeling in shaping children's diets[34, 35]. Crucially, multivariable regression models revealed no significant three-way interactions (parent × group × time) across any biomarkers. Rather than reflecting a lack of statistical power, this absence of a differential trajectory suggests a structural reality: the fundamental pathway of parent-to-child dietary transmission remained

largely immutable despite the intervention. The persistent predictive effect of parental Na/K ratio highlights that the household dietary environment functions as an independent and entrenched track, one that was not easily penetrated by the "child-to-parent" educational spillover.

While the household pathway remained stubbornly stable, individual-level dose-response analysis revealed a distinct mechanistic track within the school environment. Consistent with the analytical reduction of sodium in cafeteria lunches, students with higher in-school lunch frequency within the intervention group exhibited borderline significant, dose-dependent improvements in the Na/K ratio and urinary sodium reductions. The fact that this dose-response signal emerged parallel to the immutable household transmission pathway strongly supports a dual-track mechanism: the physical modification of the school food environment successfully provided a localized "protective shield" during school hours, but this targeted environmental change operated independently of the unmodified home environment.

The convergence of these three-stage analyses traces a coherent and critical narrative regarding pediatric sodium reduction. The intervention successfully modified the school food environment (yielding targeted downstream physiological benefits) and improved students' cognitive metrics (knowledge and attitudes). However, the translation of this cognitive improvement into comprehensive, 24-hour physiological change was structurally bottlenecked by the unchanged household dietary track. These findings challenge the assumption underlying school-based salt reduction programs that children can effectively transfer health messages to their families and induce substantial dietary change among adult household members[19, 36]. They further demonstrate that while school environment modification is necessary, it is insufficient to offset the dominant influence of home cooking, which remains the principal source of dietary sodium exposure in Chinese households[8]. Future public health strategies must move beyond school-based education and directly target the behavior of household meal preparers.

4.3 Limitations

This study has several limitations. First, the design was quasi-experimental. Cities, not schools, were allocated to intervention and control, and unmeasured differences between the two cities may have contributed to the observed effects. Second, the sample size (20 schools, 487 pairs) and the use of a single 24-hour urine collection per time point limited statistical power, particularly for interaction and subgroup analyses. Third, dietary intake and household cooking practices were not directly measured. The mechanisms proposed here for the potassium increase and the sodium null result therefore remain inferences, not demonstrated pathways. Fourth, the trial was conducted in two cities in Jiangsu Province, and the findings may not generalize to regions with different dietary patterns. Fifth, intervention fidelity metrics were not systematically analyzed, and the concurrent decline in control school cafeteria sodium, together with the routine health education both groups received, means the estimated effects are likely conservative.

4.6 Implications for Practice and Future Research

Although the intervention improved knowledge, attitudes, parent sodium intake, and the school food environment, it did not reduce children's 24-hour sodium excretion. This finding suggests that school-based interventions alone may be insufficient to achieve meaningful reductions in children's sodium intake. In China, where much of dietary sodium is still derived from salt and soy sauce added during home cooking, school-based strategies are likely to be more effective when combined with interventions targeting household meal preparation.

Several practical approaches warrant consideration. Salt-restriction spoons and low-sodium salt substitutes have demonstrated effectiveness in randomized trials, including benefits for cardiovascular outcomes[37]. Cooking workshops that actively involve grandparents may help overcome barriers unique to multi-generational households[38]. Furthermore, the comprehensive community-based model currently under evaluation in China, which integrates school

education, home-cook training, and restaurant sodium-reduction standards, represents a logical extension of the intervention framework tested in the present study[39].

Future studies should consider urinary Na/K ratio as a co-primary outcome because it may be more responsive to dietary change than sodium alone. Repeated 24-hour urine collections would reduce within-person variability and improve statistical power. Direct measurement of cafeteria sodium content using ICP-MS should be adopted as a standard implementation-fidelity indicator. In addition, school-level randomization within a single geographic area would reduce potential confounding by regional differences. Finally, dietary assessment methods capable of distinguishing school-based and home-based food consumption are needed to better attribute intervention effects to specific exposure settings.

Conclusion

This school-based salt reduction program improved knowledge, attitudes, parent sodium intake, and the school food environment, but did not reduce children's 24-hour urinary sodium excretion. These findings suggest that school-based interventions alone may be insufficient to achieve meaningful reductions in children's sodium intake. In China, where dietary sodium is largely derived from home cooking, effective sodium reduction strategies will likely require direct engagement of household meal preparers.

Declarations

Ethics approval and consent to participate

The study protocol was approved by the Ethics Review Committee of the Jiangsu Provincial Center for Disease Control and Prevention (JSJK2021-B014-01). Written informed consent was obtained from all participating parents, with child assent, prior to data collection.

Conflict of Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Author Contribution

Z.Z. and D.P. contributed equally to this work and share first authorship.Z.Z. performed the statistical analyses, interpreted the data, and drafted the manuscript. D.P. participated in data collection, data curation, and manuscript revision. H.Z. participated in data collection and investigation. R.X., J.Y., and T.M. participated in data collection and investigation. C.Q. and H.X. contributed to methodology development, data validation, and critical revision of the manuscript. G.S. and S.Z. conceived and designed the study, acquired funding, supervised the project, and critically

revised the manuscript. G.S. and S.Z. contributed equally as corresponding authors.All authors have read and approved the final manuscript.

Data Availability

The datasets generated and analyzed during the current study are not publicly available because they contain information from human participants, including primary school students and their parents, and are therefore subject to ethical and privacy restrictions. The datasets are available from the corresponding authors upon reasonable request. The corresponding authors had full access to all study data and take responsibility for the integrity of the data and the accuracy of the data analysis.

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Figures

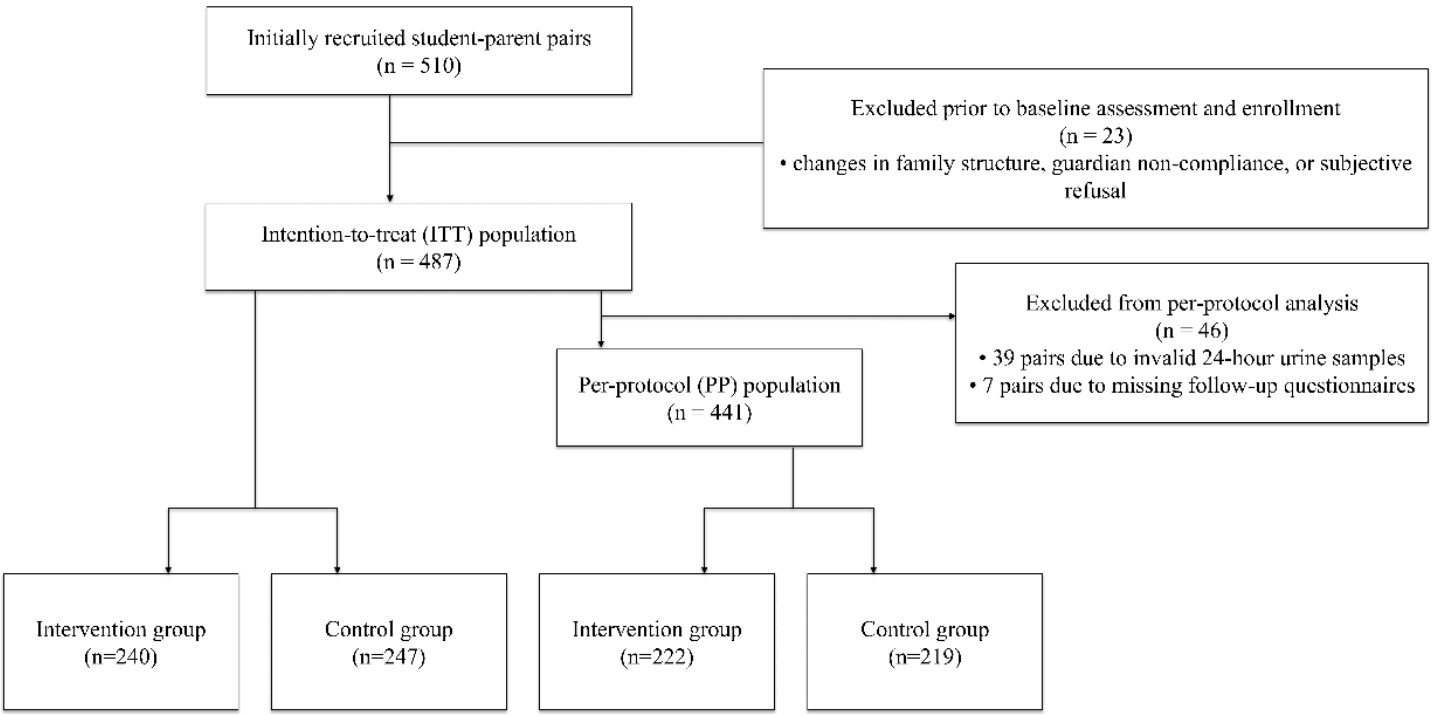


Figure 1

Participant flowchart of the study.

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