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Original article

24h-Sodium excretion and hydration status in children and adolescents - Results of the DONALD Study

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SUMMARY

Background & aims: To describe actual data on intake, sources, age and time trends of urinary sodium excretion and to analyze the potential association between urinary sodium excretion and hydration status respective beverage consumption in a sample of healthy German children and adolescents.
Methods: Data of 1575 24 h-urine samples and weighed dietary records of 499 children (249 boys) aged 4–18 years of the Dortmund Nutritional and Anthropometric Longitudinally Designed (DONALD) Study collected in 2003–2009 were analyzed using linear mixed effects regression models. Free water reserve (FWR, measured urine volume (ml/24 h) minus the obligatory urine volume (ml/24 h)) was used as a marker for hydration status.
Results: Urinary sodium excretion was between 1.4 g/day and 3.2 g/day, showing a positive age trend but remained stable during the study period. In girls, there was a significant positive association between salt excretion and FWR ($p = 0.04$). Per g/MJ urinary sodium excretion, beverage intake increased by 0.05 g/MJ (boys) or 0.08 g/MJ (girls).
Conclusion: Hydration status was not affected by salt intake in this sample of healthy children and adolescents in a western life style, due to a compensatory increase in beverage consumption.

1. Introduction

Dietary salt (sodium chloride, NaCl) is an important regulator of blood pressure among hypertensive and normotensive individuals[1] Even during childhood, a linear relationship between urinary sodium which closely reflects dietary salt/sodium intake and systolic blood pressure was shown.[2] The US Dietary Reference Intakes assessed a tolerable upper intake level (UL) of sodium increasing with age from 1.5 g/day (1–3 years) to 1.9 g/day (4–8 years), 2.2 g/day (9–13 years) and 2.3 g/day (>14 years).[3] However, dietary data point to much higher dietary salt intakes in children as well as in adults.[4–6] A reduction of salt intake soon during childhood therefore seems to be reasonable from a preventive perspective.[7]

Another potential but widely disregarded adverse effect of a high salt intake is its probable impact on hydrations status.[2,8] The hydration status of the body is mainly influenced by beverage and food consumption,[9] but dietary salt might also have an effect, as the excretion of excess sodium requires the excretion of water. Water is one of the most essential nutrients,[10] and the optimal functioning of the body requires a good hydration status.[11] From a long-term perspective, a mild chronic dehydration is associated with an increased risk for urolithiasis, constipation or urinary tract infections; for bladder and colon cancer the evidence of such an association is inconsistent.[12]

Therefore, the aim of this evaluation was (a) to describe actual data on intake, sources, age and time trends of dietary salt using urinary sodium excretion as a biomarker (b) to describe hydration status and its age and time trends and (c) to analyze the potential association between urinary sodium excretion and hydration status respective beverage consumption in a sample of healthy German children and adolescents. For this purpose, data of the Dortmund Nutritional and Anthropometric Longitudinally Designed (DONALD) Study collected in 2003–2009 were used.

2. Methods

2.1. Study design

The DONALD Study is an on-going open cohort study that started in 1985 in Dortmund, Germany and investigates the relationship between nutrition, development, metabolism, and endocrinum during childhood and adolescence. Healthy newborns from

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Dortmund and surrounding communities are recruited at age 3 months and are followed with at least annual examinations until early adulthood. To date, about 600 children are participating. Details of the study design and assessment procedures have previously been published.[13]

In brief, each year the participants, or their parents respectively, are asked to complete a 3-day weighed food record. This record supplies detailed information on the kind and amount of foods and beverages consumed. The participants themselves chose the first day of dietary recording within a given period of time after the anthropometric measurements and medical examination. Beginning at age 3 or 4 years, 24-h urine samples are collected on their third day of the dietary recording. An additional visit at the study centre includes anthropometric measurements and interviews on life-style and health-related issues.

All examinations and assessments were performed with parental and later on with the children's written consent. The study was approved by the ethical committee of the Rheinische Friedrich-Wilhelms-University Bonn.

2.2. Study sample

The study sample for this analysis consisted of a subgroup of DONALD participants between 4 and 18 years of age whose 24-h urine was collected between January 2003 and December 2009 ($N = 1985$ urine samples). Quality control, e.g. collection time < 20 h, illness, or broken cooling, resulted in a rejection of 164 collections (8.3%). Urine samples having a daily creatinine excretion of <0.1 mmol/(kg/d) were excluded to minimize errors in urine collection ($N = 54$, 3.0%).

For 191 (10.8%) urine collections, no parallel one-day food record was available.

Thus, the final sample consisted of 499 children (249 boys, 250 girls) with 1575 24 h-urine samples and corresponding dietary records (Table 1). The individual number of 24-h urine samples and corresponding dietary records ranged from 1 (130 children) to 7 (20 children) (Table 1).

2.3. Urine sampling and analysis

For the 24-h urine collection, the children and their caregivers received personal and written instructions on how to collect complete 24-h urine samples. The time of the start (discard of the first micturition of the start day) and finish of the urine collection (the first micturition of the following day) should be recorded in a questionnaire, together with the time of any lost specimens and intake of medications during the urine collection period. The urine samples were immediately stored in preservative-free, Extran-cleaned (Extran, MA03; Merck, Darmstadt, Germany) 1-L plastic containers at less than −12 °C. Salt excretion (NaCl) was calculated from analyzed (24 h-urine) sodium (1 g salt = 393 mg sodium).

As marker of hydration status the free water reserve (FWR, ml/24 h) was used, as determined and described previously.[10] FWR was calculated as the measured urine volume (ml/24 h) minus the obligatory urine volume (ml/24 h). The obligatory urine volume is defined as the water volume necessary to excrete 24 h urine solutes at the lower limit of maximum urine osmolality (excreted 24h solutes (mosm/24 h)/830 mosm/1000 g). Here, 830 mosm/1000 g is the mean maximum urine osmolality, established by renal concentrating test in healthy children, minus 2 SD values. Since concentration ability decreases not until age of 20,[14,15] this value can also be used to establish FWR in adolescents (14–18 years).

Positive values of FWR indicate euhydration, negative values the risk of hypo-hydration.[10]

2.4. Dietary survey

In the DONALD Study, weighed dietary records are used for the assessment of food consumption and nutrient intake. For the present analysis only the record day parallel to the urine collection was used. In general, all foods and beverages before consumption as well as leftovers are weighed and recorded by the parents of the children or by the older subjects themselves on three consecutive days. Semi-quantitative recording (e.g. numbers of glasses, cups) is allowed, if weighing is not possible. The use of discretionary salt for cooking and added at the table at home is only recorded qualitatively, but not quantitatively. Therefore, food records in the DONALD study only give estimated salt intakes from processed foods including inherent sodium.

Energy, nutrient and food group intakes were calculated using our in-house nutrient database LEBTAB, which contains detailed data on the energy and nutrient content of all recorded food items and is continuously updated.[16] The nutrient content of basic foods including milk, fruit, vegetables, or meat was taken from standard nutrient tables; the content of commercial food, e.g. bread, cheese, cold meat, ready-to-eat food was derived from simulating recipes from labeled ingredients and nutrients. If sodium content in food products has not been labeled, sodium content was estimated (bread: 440 mg/100 g, cheese and cold meat: 800 mg/100 g, ready to eat food: 400 mg/100 g, hard cheese 1250 mg/100 g).

All recorded food items were assigned to one of the following food groups, which potentially affect salt intake:

- Bread: bread, tortilla, wraps
- Ready-to-eat cereals (RTEC): e.g. cornflakes (not including natural cereals, e.g. rolled oats)
- Cheese: e.g. camembert, gouda, fresh cheese
- Cold meat: e.g. sausage, salami
- Convenience food: all commercial savory products, frozen, canned or instant, hot or cold (e.g., salads and soups), all-in-one-meals or courses (e.g., pizza or meat dishes).
- Commonly unsalted food (e.g. fruit, muesli, milk, cakes and cookies, confectionary)
- Commonly salted food (e.g. rice, pasta, potatoes, meat, fish, savory snack food, vegetables)
- Beverages: e.g. fruit juices, sugar sweetened beverages, light soft drinks, water, tea, excluding milk)

2.5. Additional variables

The DONALD Study participants are measured at each visit according to standard anthropometric procedures.[13] They are dressed in underwear and are barefoot. Standing height is

Table 1
Sample characteristics of 4–18-year old participants of the DONALD Study (1575 measurements).

	4–8 years	9–13 years	14–18 years
Boys			
Subjects [n]	115	136	104
Measurements [n]	219	324	243
Age [ys] [a]	6.0 (5.0; 7.0)	10.1 (9.0; 12.0)	16.0 (15.0; 17.0)
BMI [kg/m^2] [a]	15.5 (14.8; 16.5)	17.2 (16.0; 19.6)	21.2 (19.3; 25.6)
Girls			
Subjects [n]	114	133	104
Measurements [n]	219	343	228
Age [ys] [a]	5.9 (5.0; 7.0)	10.1 (9.0; 12.0)	16.0 (15.0; 17.0)
BMI [kg/m^2] [a]	15.3 (14.5; 16.1)	17.1 (15.7; 18.9)	20.8 (18.9; 23.5)

[a] Values are medians (quartile 1, quartile 3).