Public Health Nutrition: 11(3), 300–306 DOI: 10.1017/S1368980007000328

# Potential renal acid load in the diet of children and adolescents: impact of food groups, age and time trends

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Submitted 2 October 2006: Accepted 3 April 2007: First published online 5 July 2007

## Abstract

*Objective:* The impact of acid–base balance on health is widely accepted. Here, we describe the potential renal acid load (PRAL) in the diet of healthy German children and adolescents.

*Design:* The Dortmund Nutritional and Anthropometric Longitudinally Designed (DONALD) Study is an ongoing longitudinal (open cohort) study (start 1985) collecting detailed data on diet, growth, development and metabolism in infants, children and adolescents.

*Setting:* Research Institute of Child Nutrition, Dortmund.

*Subjects:* Seven hundred and twenty children and adolescents (351 boys and 369 girls), aged 3–18 years, provided 4187 yearly collected 3-day dietary records between 1995 and 2005.

*Results:* Mean daily PRAL was positive in all age/sex groups (6–21 mEq day$^{-1}$), and significantly higher in boys than in girls after the age of 8 years, even when calculated as mEq MJ$^{-1}$. Fruits, vegetables and potatoes had a negative impact on PRAL; cheese, dairy products, cereals/bread and meat/fish/eggs had a positive impact. In a mixed linear model, PRAL, expressed as mEq day$^{-1}$ and mEq MJ$^{-1}$, remained stable during the study period, since time trends of PRAL-relevant food groups countervail each other. PRAL intake (mEq MJ$^{-1}$) was significantly positively associated ($P < 0.0001$) with fat intake (% of energy intake, %*E*), but negatively with carbohydrate intake (%*E*; $P < 0.0001$).

*Conclusions:* The analysis of dietary habits in our sample of German children and adolescents showed a moderate excess of acidity. Especially older boys should be encouraged to eat more potatoes and vegetables as good sources of dietary alkalinity. The PRAL concept is compatible with current concepts for a healthy diet.

**Keywords**
Potential renal acid load
Children
Adolescents
Dietary records
Food groups
Trends

Diet influences the acid–base balance of the body. Several studies have shown that dietary data can be used as an estimate for net endogenous acid production[1–4]. Some dietary factors contribute to dietary acid load, including sulphur from the catabolism of sulphur amino acids, which are highest in animal protein, nuts and cereals, and phosphorus, which is mainly supplied by meat and dairy products. Potassium and magnesium, mainly contained in plant foods, and calcium, being present both in plant foods and dairy products, are determinants of alkali load.

To measure the total dietary acid load, different approaches exist. Frassetto *et al.*[4] suggested the ratio of protein and potassium as an indicator of the acid–base balance, taking into account only one component from each side of acid–base balance. Another established method of estimating acid loads of foods or diets is by calculating the potential renal acid load (PRAL). PRAL provides an estimate of the production of endogenous acid that exceeds the level of alkali produced for given amounts of food ingested daily. The concept of PRAL calculation is physiologically based and takes into account different intestinal absorption rates of individual minerals and of sulphur-containing protein, as well as the amount of sulphate produced from metabolised proteins. This method of calculation was experimentally validated not only in healthy adults[2] but also in children and adolescents at ages with relatively low growth rates[3]. With PRAL, acid loads and renal net acid excretion (NAE) can be reasonably estimated from diet composition.

Although the impact of acid–base balance on health, especially of bone[5,6] and kidney[7,8], is widely accepted, only few data on the dietary acid load in healthy people, especially children, are available. In the present paper, we describe the PRAL of the diet of healthy German children and adolescents from the Dortmund Nutritional and Anthropometric Longitudinally Designed (DONALD)

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Study, the impact of nutrients and food groups on PRAL as well as age and time trends and differences between gender.

## Methods

### *Study design*

The DONALD Study is an ongoing longitudinal (open cohort) study (start 1985) collecting detailed data on diet, growth, development and metabolism between infancy and adulthood (once a year for subjects older than 2 years). Details have been described elsewhere[6,9].

The starting study sample included infants, children and adolescents recruited from earlier cross-sectional studies in schools and kindergartens ($n \approx 470$). After 1989, infants are recruited and followed up at least until the age of 18 years.

The regular assessments (quarterly for infants, bi-annually for toddlers, others yearly) include records of dietary intake and behaviour, anthropometry, urine sampling, interviews on lifestyle and health-related issues, and a medical examination[10].

The Scientific Committee of the Research Institute of Child Nutrition and the Ethic Commission of the University of Bonn have approved the DONALD Study, which is observational and non-invasive. All examinations and assessments are performed with parental consent and later on with the children's consent.

### *Study sample*

For the present evaluation, we selected 4187 3-day dietary records of 720 children and adolescents (351 boys and 369 girls) aged 3–18 years between 1995 and 2005 from the available pool of records (Table 1). Records available per participant ranged from one ($N = 96$, 13.3% of the total sample) to 11 ($N = 73$, 10.1%). Between 420 (2003) and 319 (2005) dietary records were collected per study year. For further analysis, the study sample was stratified by age group (3–7 years; 8–14 years; 15–18 years), the latter two groups being stratified by gender.

### *Dietary survey*

Parents of the children or the older subjects themselves weighed and recorded all foods and fluids consumed, as well as recipes of home-prepared meals using electronic food scales (±1 g) on three consecutive days, additionally recording all medicines and supplements taken. Semi-quantitative recording (e.g. number of spoons, scoops) was allowed if weighing was not possible. However, in 75% of the completed records, more than 90% of the food items were weighed[11].

Energy and nutrient intakes were calculated using our nutrient database LEBTAB, which is continuously updated by all new food items recorded. Nutrient contents of staple foods were taken from standard nutrient tables, predominantly German (48% of items) and US (18% of items) nutrient tables. Nutrient contents of composite foods, particularly commercial food products, are generated by use of recipes or recipe simulation using labelled nutrient contents and ingredients[12].

At present, LEBTAB contains about 6000 food items (15% staple foods, 77% composites and commercial products including commercial infant food, and 8% special preparations).

### *Definition of food groups*

After breaking down the recipes of composite foods (e.g. pizza, ready-to-eat meals), the following food groups were aggregated:

- Fruits, including fresh, frozen and canned fruit, 100% juices.
- Vegetables, including fresh, frozen and canned vegetables, 100% juices.
- Cereals/bread, including rice, pasta, breakfast cereals, cakes, biscuits.
- Potatoes, including boiled, mashed or fried potatoes.
- Dairy products (whey-based), including milk for drinking and cooking, milk puddings, yoghurts.
- Cheese, including curd, fresh and cottage cheese, soft (type camembert) and hard cheese (type gouda, emmentaler).
- Meat/fish/egg, including sausage, canned meat or fish.
- All other foods, including fat, oils, confectionery, beverages and pulses.

### *Statistical analysis*

SAS® procedures (Version 6.12; Statistical Analysis System) were used for data analysis. PRAL of the records was estimated using the algorithm[2,3]:

$$\begin{aligned} \text{PRAL}\,(\text{mEq day}^{-1}) = {} & \text{protein}\,(\text{g day}^{-1}) \times 0.4888 \\ & + \text{phosphorus}\,(\text{mg day}^{-1}) \times 0.0366 \\ & - \text{potassium}\,(\text{mg day}^{-1}) \times 0.021 \\ & - \text{magnesium}\,(\text{mg day}^{-1}) \times 0.0263. \end{aligned}$$

In contrast to the original PRAL model[2,3], calcium was not included in the algorithm, since calcium absorption varies considerably during childhood and adolescences due to growth-dependent skeletal mineral accrual.

Food group and nutrient intakes and % PRAL from food groups were calculated as individual means of the three recorded days.

Since energy and total food intakes increase with age during childhood and adolescence and differ between genders, the dietary intakes were adjusted for energy intake by calculating nutrient and food group densities. Thus, potential age trends and gender differences of dietary quality with respect to acid–base balance could be identified.

Results are presented as mean values ± standard deviations. To analyse the associations between time, age, gender and other dietary components, and PRAL, a mixed linear model was used, in which the means of the data, the covariance structure and the effect of repeated measurements were measured (PROC MIX). An exponential structure of covariance was specified to consider the correlation of repeated measurements dependent on the absolute time interval of repeated measurements within the same subject. Trend results were noted (see $\beta$ in Tables 2–4): increase (+), decrease (−). Significant differences were taken at $P < 0.05$.

## Results

Table 1 describes overall diet of the sample. Energy and total food intake was significantly higher in boys than in girls. Carbohydrates contributed more than half of energy intake and fat yielded about 35% of energy intake. Protein intake (% energy intake, %*E*) was about 13–14%, with significantly higher intakes in older boys than in girls.

Table 2 shows the mean intakes of PRAL and contribution of different food groups to PRAL. Mean daily PRAL (mEq day$^{-1}$) was positive in all age/sex groups. PRAL was significantly higher in boys than in girls after the age of 8 years. These gender differences persisted when calculating PRAL as mEq MJ$^{-1}$.

Three food groups (fruits, vegetables and potatoes) had a negative impact on daily PRAL, four food groups (cheese, dairy products, cereals/bread and meat/fish/eggs) had a positive impact (Table 2). Significant gender differences were found for the PRAL contributions of potatoes, dairy products, cereals/bread, meat/fish/eggs and cheese, the latter only in 15–18-year-olds, but no gender differences were found for fruits and vegetables. This ranking of food groups according to PRAL contribution was similar in all age groups.

**Table 1** Sample and diet characteristics in 720 German children and adolescents from the DONALD Study (4187 dietary records), means ± SD

| | 3–7 years | 8–14 years | | 15–18 years | |
|---|---|---|---|---|---|
| | Boys and girls | Boys | Girls | Boys | Girls |
| Number of records | 1648 | 946 | 945 | 324 | 324 |
| Number of persons | 519 | 220 | 225 | 104 | 103 |
| Age (years) | 5.0 ± 1.4 | 10.8 ± 2.0 | 10.8 ± 2.0 | 16.5 ± 1.1 | 16.5 ± 1.1 |
| Weight (kg) | 19.6 ± 4.4† | 40.8 ± 12.5 | 40.3 ± 13.2 | 69.7 ± 11.8 | 62.1 ± 11.4* |
| Height (m) | 1.11 ± 0.11* | 1.48 ± 0.14 | 1.47 ± 0.14† | 1.80 ± 0.07 | 1.70 ± 0.06* |
| BMI (kg m$^{-2}$) | 15.7 ± 1.4 | 18.0 ± 2.8 | 18.1 ± 3.2 | 21.5 ± 3.1 | 21.7 ± 3.4 |
| Energy (MJ) | 5.4 ± 1.1* | 8.1 ± 1.7 | 7.0 ± 1.4* | 10.3 ± 2.3 | 7.5 ± 1.8* |
| Total food intake (g) | 1466 ± 363* | 2161 ± 610 | 1882 ± 492* | 3067 ± 842 | 2381 ± 742* |
| Energy density (kJ g$^{-1}$) | 3.8 ± 0.7 | 3.9 ± 0.7 | 3.8 ± 0.7 | 3.5 ± 0.7 | 3.3 ± 0.9 |
| Protein (%*E*) | 12.6 ± 2.0 | 13.0 ± 2.1 | 12.8 ± 2.1 | 13.8 ± 2.1 | 13.1 ± 2.1† |
| Carbohydrates (%*E*) | 51.9 ± 6.0 | 51.9 ± 5.9 | 52.0 ± 5.9 | 51.3 ± 6.9 | 53.1 ± 6.8 |
| Fat (%*E*) | 35.5 ± 5.4 | 35.1 ± 5.5 | 35.2 ± 5.4 | 35.0 ± 6.5 | 33.8 ± 6.3 |

SD – standard deviation; BMI – body mass index; %*E* – percentage of energy intake.
Significant gender differences (mixed linear model, including age and time trends): *$P < 0.0001$; †$P < 0.01$.

**Table 2** Intake of PRAL (mEq day$^{-1}$) and contribution of food groups to PRAL (mEq day$^{-1}$) in 720 German children and adolescents from the DONALD Study (4187 dietary records), means ± SD

| | 3–7 years | 8–14 years | | 15–18 years | |
|---|---|---|---|---|---|
| | Boys and girls | Boys | Girls | Boys | Girls |
| PRAL | | | | | |
| (mEq day$^{-1}$) | 5.9 ± 8.6 | 13.3 ± 12.4 | 9.5 ± 10.3* | 20.5 ± 15.1 | 8.6 ± 13.1* |
| (mEq MJ$^{-1}$ day$^{-1}$) | 1.1 ± 1.5 | 1.6 ± 1.5 | 1.4 ± 1.5† | 2.0 ± 1.4 | 1.1 ± 1.8* |
| Fruits (mEq day$^{-1}$) | −7.75 ± 4.98 | −8.01 ± 6.24 | −7.95 ± 5.77 | −8.85 ± 7.96 | −9.49 ± 7.54 |
| Vegetables (mEq day$^{-1}$) | −3.35 ± 2.40 | −4.74 ± 3.47 | −4.54 ± 3.34 | −6.41 ± 4.10 | −5.76 ± 3.90 |
| Potatoes (mEq day$^{-1}$) | −2.83 ± 2.25† | −4.46 ± 3.43 | −3.88 ± 3.05‡ | −5.50 ± 4.27 | −4.36 ± 3.78** |
| Cheese*** (mEq day$^{-1}$) | 3.87 ± 3.75 | 6.80 ± 6.39 | 6.07 ± 5.68 | 11.06 ± 8.92 | 7.97 ± 6.53‡ |
| Dairy products**** (mEq day$^{-1}$) | 4.08 ± 2.54** | 5.48 ± 3.34 | 4.16 ± 2.60* | 5.91 ± 3.66 | 3.88 ± 2.65* |
| Cereals/bread (mEq day$^{-1}$) | 6.16 ± 2.61† | 9.60 ± 3.81 | 8.28 ± 2.98* | 12.80 ± 5.18 | 9.24 ± 3.67* |
| Meat/fish/egg (mEq day$^{-1}$) | 6.33 ± 3.05** | 9.98 ± 5.12 | 8.39 ± 4.20* | 14.08 ± 7.02 | 9.08 ± 5.15* |
| All other foods (mEq day$^{-1}$) | −0.57 ± 1.33 | −1.37 ± 2.31 | −1.04 ± 1.86† | −2.74 ± 3.73 | −2.00 ± 2.59 |

PRAL – potential renal acid load; SD – standard deviation.
Significant gender differences (mixed linear model, including age and time trends): *$P < 0.0001$; †$P < 0.01$; ‡$P < 0.001$; **$P < 0.05$.
***Including curd, fresh and cottage cheese, soft (type camembert) and hard cheese (type gouda, emmentaler).
****Whey-based dairy products, including milk for drinking and cooking, milk puddings, yoghurts.

Figure 1 shows the PRAL content per 100 g food group, reflecting the food selection and consumption amounts of single foods within the food groups as consumed by the DONALD Study sample. Here, potato was the food group with the highest alkalinity, whereas the median PRAL as well as the interquartile range of cheese was highest.

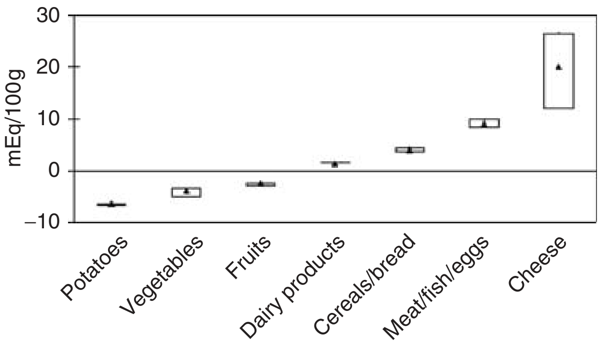


**Fig. 1** Distribution of PRAL (mEq) per 100 g food group as eaten by 720 German children and adolescents from the DONALD Study (4187 dietary records), box = interquartile range, triangle = median (for food group aggregation see Methods; PRAL – potential renal acid load)

Table 3 shows mean daily intakes of PRAL-related nutrients and food groups, calculated per day and per MJ and day. Absolute nutrient intakes increased with age and were significantly higher in boys than in girls. Significant gender differences were found in 15–18-year-olds for protein and potassium (g or mg MJ$^{-1}$) and in 8–14-year-olds for phosphorus (mg MJ$^{-1}$).

Figure 2 shows the distribution of fat and carbohydrate intakes in age- and gender-specific quartiles of PRAL (mEq MJ$^{-1}$). Fat increased and carbohydrates decreased with increasing quartile of PRAL. In a mixed linear model, PRAL intake (mEq MJ$^{-1}$) was positively associated ($P<0.0001$) with fat intake (% of energy intake, %*E*) in 3–7-year-old boys and girls ($\beta = 0.9$), 8–18-year-old boys ($\beta = 0.05$) and girls ($\beta = 0.09$), but negatively with carbohydrate intake (%*E*; $P<0.0001$; $\beta = -0.12$, $-0.09$ and $-0.13$, respectively) (controlling for age, time and gender; data not shown).

**Table 3** Intake of PRAL and acid–base-related nutrients and food groups, calculated as intakes per day and per MJ day$^{-1}$ in 720 German children and adolescents from the DONALD Study (4187 dietary records), means ± SD

| | 3–7 years | 8–14 years | | 15–18 years | |
|---|---|---|---|---|---|
| | Boys and girls | Boys | Girls | Boys | Girls |
| Protein | | | | | |
| (g) | 40.5 ± 9.9* | 62.3 ± 16.0 | 52.9 ± 12.6* | 83.8 ± 20.9 | 58.4 ± 14.7* |
| (g MJ$^{-1}$) | 7.5 ± 1.2 | 7.7 ± 1.2 | 7.6 ± 1.3 | 8.2 ± 1.3 | 7.9 ± 1.3† |
| Phosphorus | | | | | |
| (mg) | 796 ± 208* | 1185 ± 321 | 1001 ± 255* | 1528 ± 408 | 1095 ± 301* |
| (mg MJ$^{-1}$) | 148 ± 28 | 147 ± 27 | 144 ± 26** | 150 ± 26 | 147 ± 28 |
| Potassium | | | | | |
| (mg) | 1814 ± 453* | 2536 ± 715 | 2222 ± 595* | 3181 ± 918 | 2513 ± 701* |
| (mg MJ$^{-1}$) | 339 ± 67 | 316 ± 66 | 321 ± 66 | 312 ± 65 | 340 ± 80‡ |
| Magnesium | | | | | |
| (mg) | 186 ± 52* | 275 ± 82 | 240 ± 65* | 363 ± 111 | 273 ± 81* |
| (mg MJ$^{-1}$) | 35 ± 7 | 34 ± 8 | 35 ± 8 | 36 ± 8 | 37 ± 10 |
| Fruits | | | | | |
| (g day$^{-1}$) | 280 ± 187 | 302 ± 240 | 291 ± 221 | 331 ± 305 | 341 ± 278 |
| (g MJ$^{-1}$) | 52.6 ± 33.7 | 37.6 ± 28.6 | 41.8 ± 29.8† | 31.2 ± 26.4 | 46.1 ± 36.1* |
| Vegetables | | | | | |
| (g day$^{-1}$) | 79 ± 55 | 112 ± 82 | 110 ± 74 | 149 ± 88 | 133 ± 81 |
| (g MJ$^{-1}$) | 15.0 ± 10.7† | 14.2 ± 10.4 | 16.2 ± 11.1** | 14.9 ± 90.2 | 18.4 ± 13.0‡ |
| Potatoes | | | | | |
| (g day$^{-1}$) | 45 ± 35† | 70 ± 53 | 61 ± 47‡ | 85 ± 66 | 68 ± 59** |
| (g MJ$^{-1}$) | 8.4 ± 6.5 | 8.8 ± 6.5 | 8.9 ± 7.0 | 8.7 ± 6.9 | 9.2 ± 8.3 |
| Cheese*** | | | | | |
| (g day$^{-1}$) | 27 ± 30 | 38 ± 40 | 35 ± 36 | 54 ± 44 | 43 ± 41† |
| (g MJ$^{-1}$) | 5.2 ± 5.5 | 4.8 ± 4.8 | 5.1 ± 5.2 | 5.3 ± 4.0 | 5.8 ± 5.7 |
| Dairy products**** | | | | | |
| (g day$^{-1}$) | 277 ± 168† | 373 ± 222 | 289 ± 173* | 405 ± 249 | 271 ± 179* |
| (g MJ$^{-1}$) | 51.7 ± 29.9 | 46.4 ± 26.2 | 41.2 ± 23.0‡ | 39.8 ± 23.5 | 36.7 ± 24.2 |
| Cereals/bread | | | | | |
| (g day$^{-1}$) | 148 ± 58** | 237 ± 87 | 205 ± 70* | 318 ± 120 | 235 ± 88* |
| (g MJ$^{-1}$) | 27.5 ± 9.1 | 29.5 ± 9.1 | 29.7 ± 9.1 | 31.1 ± 9.8 | 31.5 ± 10.2 |
| Meat/fish/egg | | | | | |
| (g day$^{-1}$) | 72 ± 35** | 110 ± 56 | 93 ± 47* | 153 ± 80 | 98 ± 56* |
| (g MJ$^{-1}$) | 13.4 ± 6.1 | 13.8 ± 6.4 | 13.4 ± 6.4 | 15.2 ± 7.5 | 13.1 ± 7.2† |

PRAL – potential renal acid load; SD – standard deviation.
Significant gender differences (mixed linear model, including age and time trends): *$P<0.0001$; †$P<0.01$; ‡$P<0.001$; **$P<0.05$.
***Including curd, fresh and cottage cheese, soft (type camembert) and hard cheese (type gouda, emmentaler).
****Whey-based dairy products, including milk for drinking and cooking, milk puddings, yoghurts.

Table 4 shows the age and time trends of energy, PRAL, nutrients and food group intakes, each calculated per MJ, estimated by a mixed linear model. Energy intake increased with age, but remained stable over the study period. Also PRAL, expressed as $mEq\,day^{-1}$ and $mEq\,MJ^{-1}$, showed no time trends. Significant positive age trends were found in the younger age group and 8–18-year-old boys, but not in girls.

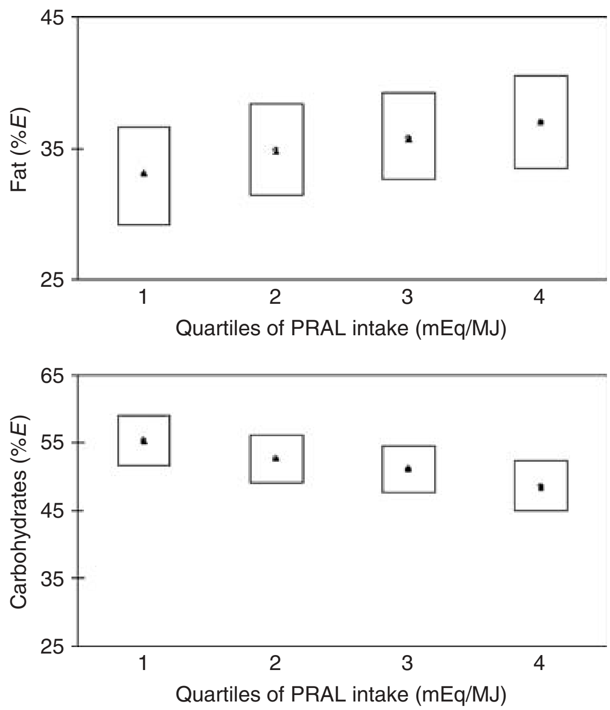


**Fig. 2** Distribution of fat intake and carbohydrate intake (%*E*; % of energy intake) in quartiles of PRAL ($mEq\,MJ^{-1}$) in 4187 dietary records in 720 German children and adolescents from the DONALD Study, box = interquartile range, triangle = median (PRAL – potential renal acid load)

With age, energy-adjusted intakes of cheese ($g\,MJ^{-1}$) decreased in the younger, but increased in the older age group. Intake of dairy products ($g\,MJ^{-1}$) decreased significantly in the total sample and intake of cereals/bread ($g\,MJ^{-1}$) increased only in the youngest age group. Intake of vegetables ($g\,MJ^{-1}$) showed neither age nor time trends.

During the study period, dairy products intake ($g\,MJ^{-1}$) decreased in all age groups (non-significant in 8–18-year-old girls), whereas intake of cereals/bread ($g\,MJ^{-1}$) increased. Intake of fruits and potatoes significantly decreased during the study period in the younger age group.

## Discussion

In the DONALD Study sample, the diet of children and adolescents yielded on average a slight excess of acidifying nutrients. This is in accordance with an evaluation of the dietary acid–base balance in British teenagers (nearly $+70\,mEq\,day^{-1}$ in boys and $+54\,mEq\,day^{-1}$ in girls)[13]. The impact of such dietary habits on health is no longer controversial; however, the effects on bone stability[6], renal nitrogen wasting[14] and nephrolithiasis[7,8] appear to be at least partly moderate.

In the cross-sectional study of Prynne *et al.*[13] on adolescents, potatoes had the highest negative impact on the daily dietary acid load, followed by beverages, fruits and nuts and vegetables. The observed differences between our results and Prynne's study may be due to food

**Table 4** Age and time trends of total energy intake, PRAL ($mEq\,MJ^{-1}$) and acid–base-related nutrients ($g\,MJ^{-1}$ or $mg\,MJ^{-1}$) and food groups ($g\,MJ^{-1}$) in 720 German children and adolescents from the DONALD Study (4187 dietary records)

| | 3–7-year-old boys and girls | | | | 8–18-year-old boys | | | | 8–18-year-old girls | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Age | | Time | | Age | | Time | | Age | | Time | |
| | β | P | β | P | β | P | β | P | β | P | β | P |
| Energy ($MJ\,day^{-1}$) | 0.44 | **<0.0001** | 0.01 | 0.2534 | 0.37 | **<0.0001** | −0.00 | 0.9547 | 0.14 | **<0.0001** | −0.01 | 0.4623 |
| PRAL ($mEq\,day^{-1}$) | 0.87 | **<0.0001** | −0.12 | 0.1266 | 1.26 | **<0.0001** | −0.03 | 0.8214 | 0.02 | 0.8729 | −0.02 | 0.8923 |
| PRAL ($mEq\,MJ^{-1}\,day^{-1}$) | 0.07 | **0.0026** | −0.03 | 0.0642 | 0.07 | **<0.0001** | −0.01 | 0.6941 | −0.03 | 0.1330 | 0.01 | 0.7443 |
| Protein ($g\,MJ^{-1}\,day^{-1}$) | −0.06 | **0.0009** | −0.01 | 0.3315 | 0.08 | **<0.0001** | −0.01 | 0.3881 | 0.03 | 0.0540 | 0.01 | 0.4687 |
| Potassium ($mg\,MJ^{-1}\,day^{-1}$) | −9.36 | **<0.0001** | −0.32 | 0.6112 | −1.51 | 0.0520 | −0.85 | 0.2674 | 2.16 | **0.0090** | −0.81 | 0.3192 |
| Magnesium ($mg\,MJ^{-1}\,day^{-1}$) | −0.35 | **0.0022** | −0.04 | 0.5605 | 0.08 | 0.3857 | 0.02 | 0.8291 | 0.23 | **0.0250** | −0.04 | 0.6703 |
| Phosphorus ($mg\,MJ^{-1}\,day^{-1}$) | −2.84 | **<0.0001** | −0.70 | **0.0105** | 0.30 | 0.3617 | −0.63 | 0.0516 | 0.2 | 0.3701 | −0.50 | 0.1112 |
| Dairy products* ($g\,MJ^{-1}\,day^{-1}$) | −3.44 | **<0.0001** | −0.79 | **0.0073** | −1.34 | **<0.0001** | −0.63 | **0.0415** | −0.83 | **0.0028** | −0.51 | 0.0652 |
| Cheese† ($g\,MJ^{-1}\,day^{-1}$) | −0.42 | **<0.0001** | −0.06 | 0.2454 | 0.13 | **0.0121** | −0.03 | 0.5237 | 0.14 | **0.0243** | −0.02 | 0.7771 |
| Meat/fish/egg ($g\,MJ^{-1}\,day^{-1}$) | −0.06 | 0.5644 | −0.01 | 0.9140 | 0.27 | **0.0004** | 0.02 | 0.8050 | −0.04 | 0.5911 | 0.08 | 0.3100 |
| Cereals/bread ($g\,MJ^{-1}\,day^{-1}$) | 0.9 | **<0.0001** | 0.30 | **<0.0003** | 0.11 | **0.3006** | 0.42 | **<0.0001** | 0.14 | **0.1923** | 0.33 | 0.0017 |
| Vegetables ($g\,MJ^{-1}\,day^{-1}$) | 0.03 | 0.8714 | 0.13 | 0.1747 | 0.09 | 0.4962 | −0.22 | 0.0869 | 0.26 | 0.0556 | 0.07 | 0.6283 |
| Fruits ($g\,MJ\,day^{-1}$) | −4.65 | **<0.0001** | 1.28 | **<0.0001** | −1.23 | **0.0003** | 0.61 | 0.0751 | 0.32 | 0.4103 | −0.39 | 0.3004 |
| Potatoes ($g\,MJ^{-1}\,day^{-1}$) | 0.16 | 0.1432 | −0.23 | **<0.0001** | 0.04 | 0.6165 | −0.14 | 0.0521 | 0.04 | 0.5841 | 0.05 | 0.5148 |

PRAL – potential renal acid load.
Significant gender differences for energy ($MJ\,day^{-1}$; $\beta = -0.44$ girls vs. boys, $P < 0.0001$) and vegetables ($g\,MJ^{-1}\,day^{-1}$; $\beta = 1.88$, $P = 0.0032$).
* Whey-based dairy products, including milk for drinking and cooking, milk puddings, yoghurts.
† Includes curd, fresh and cottage cheese, soft (type camembert) and hard cheese (type gouda, emmentaler).

group aggregation, culture-specific dietary habits and food selections as well as differences in the used nutrient databases.

In the DONALD Study, fruits yielded the highest alkalinity, due to higher consumption amounts compared with vegetables and potatoes. Although the cheese group had the highest acidity per 100 g, their impact on overall dietary PRAL was lower than the impact of the other acidifying food groups (meat/fish/eggs and cereals/bread), because these food groups were eaten in larger amounts.

In our evaluation, we separated food groups consumed at the ingredient level (e.g. fruits, vegetables, cereals/bread), and also by the criteria of PRAL content. For this reason, we distinguished between whey-based dairy products and cheese, which was not done by others[13]. During cheese production, the alkaline whey is separated, therefore PRAL of cheese is higher than that of the original milk. The high variability of PRAL per 100 g within the cheese group is mainly due to differences in water content and to the addition of other ingredients, e.g. phosphorus-containing salts to processed cheese or herbs to some cheese preparations. Due to the lower PRAL, whey-based dairy products as a source for protein and calcium should be favoured against cheese with respect to bone health.

The increase of PRAL (mEq per day and per MJ) with age in younger children indicated an unfavourable development of dietary habits with respect to acid–base balance, i.e. the increase of cereal intake (positive PRAL) and decrease of fruit intake (negative PRAL). In older boys, this positive trend of PRAL continued, with an additional increase of cheese and meat consumption, resulting in a positive trend of protein intake ($g\,MJ^{-1}$) with age. As in the sample of British adolescents[13], significant gender differences were found in our study sample, indicated by a lower overall intake of PRAL in girls and partly gender-specific age trends of food intake. Such 'healthier' food choices and preferences in girls were also reported for different age groups in several other studies[15–18].

Up to now, no other study has examined time trends of dietary acid–base balance. We could show some significant time trends of food group intakes relevant for PRAL in our sample over 10 years. However, these single trends were partly contradictory and too small to result in significant overall time trends of PRAL.

To establish PRAL as a marker for a healthy diet, the compatibility with other concepts for a healthy diet has to be examined. Up to now, dietary recommendations mostly focus on low fat and high carbohydrate macronutrient pattern. Prynne *et al.*[13] reported that a low acid load was found in subjects who only consumed chips, baked beans, crisps, chocolate, peanuts and lager, all contributing to a high intake of potassium and also fat. Yet our analysis showed that a low PRAL intake was significantly correlated with a low fat and high carbohydrate diet, but also the combination of a low acid load with a higher fat intake was possible. Further analysis has to show which typical food pattern results in overall low or high PRAL intakes.

Some limitations of this study should be considered in interpreting our findings. The DONALD Study sample is not representative. Upper social class families are overrepresented[11]. Nevertheless, several evaluations showed no or only minor differences in dietary habits in the DONALD Study compared to the previous German National Food Consumption Survey[11,19]. Also time trends are comparable[20]. The elaborate study design of the DONALD Study causes a relatively small number of subjects, especially of older adolescents. However, the indispensable prerequisite of analyses, as presented here, is the availability of repeated dietary intake data from individuals over a long period, which is not possible in large studies with corresponding accuracy. With regard to the exactness of PRAL as an estimate of diet-dependent acid load, it has to be mentioned that the PRAL model was initially developed on the basis of average nutrient absorption coefficients for adults. Since the absorption rates partly change during periods of pronounced growth, a moderate degree of impreciseness is inherent in our findings.

In conclusion, the analysis of dietary habits in our sample of German adolescents showed a moderate excess of acidity. Especially older boys should be encouraged to eat more potatoes and vegetables as good sources of dietary alkalinity. Time trends in PRAL from single food groups can countervail each other, which may result in a lack of a time trend of total PRAL as in our sample. The PRAL concept is not only compatible with current concepts for a healthy diet but may also significantly add to them.

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