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## Higher risk of zinc deficiency in New Zealand Pacific school children compared with their Māori and European counterparts: a New Zealand national survey

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### Abstract

Few multi-ethnic national surveys have examined Zn nutriture, despite its importance for optimal growth and development during childhood. We assessed the Zn status of urban and semi-urban children aged 5–15 years from three ethnic groups in New Zealand (NZ) in the 2002 Children's National Nutrition Survey and investigated the factors predisposing them to Zn deficiency. In a 10-month cross-sectional survey, Pacific and Māori children were over-sampled permitting ethnic-specific analyses. Anthropometry, serum Zn and Zn intakes via 24 h recalls were measured. Anthropometric *z* scores were highest in Pacific children. Overall, mean adjusted serum Zn at 11 years was for males and females, respectively: 11.9 (95% CI 11.5, 12.3) and 12.5 (95% CI 12.0, 12.9)  $\mu\text{mol/l}$  in NZ European and Other (NZEO) children (*n* 395); 11.9 (95% CI 11.4, 12.4) and 12.0 (95% CI 11.4, 12.5)  $\mu\text{mol/l}$  in Māori children (*n* 379); and 11.5 (95% CI 11.1, 11.9) and 11.4 (95% CI 11.1, 11.8)  $\mu\text{mol/l}$  in Pacific children (*n* 589). The predictors of serum Zn were age, serum Se and sex for NZEO children; serum Se and age for Pacific children; and none for Māori children. Pacific children had the highest prevalence of low serum Zn (21 (95% CI 11, 30) %), followed by Māori children (16 (95% CI 12, 20) %) and NZEO children (15 (95% CI 9, 21) %). Prevalence of inadequate Zn intakes, although low, reached 8% for Pacific children who had the lowest Zn intake/kg body weight. Pacific boys but not girls with low serum Zn had a lower mean height-for-age *z*-score ( $P < 0.007$ ) than those with normal serum Zn. We conclude that the biochemical risk of Zn deficiency in Pacific children indicates a public health problem. However, a lack of concordance with the risk of dietary Zn inadequacy suggests the need for better defined cut-offs in children.

**Key words:** Serum zinc: Dietary zinc intakes: Anthropometry: Urban children

There is limited information on the Zn status of populations based on national survey data, in part because, until recently, there has been a lack of consensus on appropriate indicators of Zn status. Indeed, to date, only national surveys in the United States in 1984<sup>(1)</sup>, and more recently, the UK<sup>(2)</sup> and Mexico<sup>(3)</sup>, have published data that included a biomarker (i.e. serum Zn concentrations) of Zn status. This is unfortunate because adequate Zn nutriture is essential to support growth during childhood, reduce the risk of common infections, improve neurobehavioural function and prevent adverse pregnancy outcomes, as a result of the critical role of Zn in a wide range of biochemical, immunological and clinical functions<sup>(4)</sup>.

Recently, three indicators – a biochemical, dietary and functional indicator – have been recommended for assessing the risk of Zn deficiency in populations and for

identifying subgroups at elevated risk. The biochemical indicator is the proportion of the population with serum Zn concentrations below the appropriate lower cut-offs<sup>(5)</sup>, when the correct protocols are followed for the collection, separation and analysis of serum Zn<sup>(4)</sup>. The dietary indicator is the prevalence of usual Zn intakes below the estimated average requirements<sup>(5)</sup>. The functional indicator is the percentage with length- or height-for-age  $< -2.0$  *z* scores (i.e. stunted) and applies to the children  $< 5$  years<sup>(5)</sup>. For each indicator, a cut-off for the prevalence considered indicative of public health concern has been set<sup>(5)</sup>. At present, the 1999 nutrition survey in Mexico is the only national survey which has used these three indicators to assess the risk of Zn deficiency at the population level and to identify the subgroups at risk<sup>(3)</sup>.

In 2002, New Zealand (NZ) conducted a nationally representative survey of school children aged 5–15 years

**Abbreviations:** BW, body weight; CNS, Children's National Nutrition Survey; CRP, C-reactive protein; HAZ, height-for-age *z* scores; NZ, New Zealand; NZEO, NZ European and other; SES, socio-economic status.

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during which serum Zn and dietary Zn intakes were measured using the International Zinc Nutrition Consultative Group procedures<sup>(4)</sup> in urban and semi-urban school children from three main ethnic groups of NZ. These data provide a unique opportunity to examine the Zn status of school-aged children of Māori, Pacific and NZ European and Other (NZEO) ethnicities and to investigate factors that might predispose them to suboptimal Zn status.

## Subjects and methods

### Study design and population

The 2002 Children's National Nutrition Survey (CNS02) was a cross-sectional survey of a national sample of NZ school-aged children aged 5–15 years, conducted during the school year from February to December 2002. A school-based sampling frame of children was used with over-sampling of Māori and Pacific children to allow for ethnic-specific analysis. Details of the sampling strategy are available elsewhere<sup>(6)</sup>. Briefly, a two-stage process was used to recruit the sample involving a random selection of 172 schools on Ministry of Education rolls. Children from the designated schools were selected randomly. Recruitment from each school was in proportion to the number of students on the school roll. The total number of children invited to participate in the survey was 4728, of whom 3275 agreed to participate.

Of the 3275 participating children, only 1927 provided a non-fasting blood sample; 1348 children did not provide a blood sample, because either they refused or they were not asked because they attended a rural school. Blood samples were not collected from any of the children attending the sixty-six rural schools because it was not logistically possible to transport them from the rural areas to a laboratory in a timely manner. Sampling weights were based on the provision of a blood sample and not on survey participation as there were differences in the proportions of the three ethnicities in the blood sample group compared with the CNS02 survey sample. Weights were based on the inverse probability of selection. The weights included adjustment for differential non-response and stratification by ethnicity, age and sex to reflect the national proportions.

In the CNS02 survey, no weighting was applied to account for the effects of time of day of the blood collection, region within NZ or the onset of puberty, all variables known to have a significant effect on serum Zn and/or serum Se concentrations<sup>(4,7,8)</sup>. *Post hoc* analysis showed that there were significant differences in these variables among the three ethnic groups. Therefore, we have explored the predictors of both serum Zn concentrations and the prevalence of Zn deficiency for each of the three ethnic groups independently, using multiple linear and logistic regression models. Further details of the anthropometry, serum Zn concentrations and dietary Zn

data for the overall weighted population in the CNS02 survey are available in the study done by Parnell *et al.*<sup>(6)</sup>.

The survey received ethical approval from the Auckland Ethics Committee and thirteen regional health ethic committees. Informed written consent was obtained from both the children and their parents or guardians. Demographic data and 24 h recalls were recorded at children's homes in the presence of their parents or guardians from the last week of February 2002 to the second week of December 2002, whereas anthropometric measurements and blood samples were taken at school.

### Classification by ethnicity, socio-economic status and anthropometry

Children were assigned to one of three ethnic groups: Pacific, NZEO or Māori based on self-reports by the children or their parents or guardians. The term 'Pacific' is used here to describe the children who were identified as Samoan (55%), Tongan (24%), Cook Island Māori (16%), Niuean (10%), Tokelauan (2%), Fijian (3%) and other Pacific ethnic groups (3%). The NZEO group includes the children who were identified as NZ European (80%), Asian (10%), Other European (6%), Indian (5%) and other (4%). For children who were reported as belonging to more than one ethnic group, unequivocal rules were established to assign the children to a single ethnic category. In particular, if Māori was one of the groups reported, the participant was assigned to 'Māori'. In cases where Māori was not reported, but any of the Pacific groups were reported, then the participant was assigned to Pacific. All the remaining participants were assigned to NZEO; further details are given by Parnell *et al.*<sup>(6)</sup>. Children were also classified according to the 2001 NZ Index of Deprivation<sup>(9)</sup>. Deprivation index scores were ranked into quintiles. In the present study, children ranked in the most deprived quintile were considered to be of low socio-economic status (SES).

Height and weight were measured by trained research assistants, with children wearing light clothing and no shoes. Measurements were taken using standardised procedures and calibrated equipment<sup>(10)</sup> and the mean of the two closest measurements was used. Accuracy of anthropometric measurements was monitored throughout the survey using cumulative summation charts, as described by Parnell *et al.*<sup>(6)</sup>. Of the children, six had unacceptably extreme anthropometric *z* scores (i.e.  $>4$  SD or  $<-4$  SD), which were therefore omitted from the dataset<sup>(11)</sup>. To compare the prevalence of overweight and obesity internationally, the age- and sex-specific cut-off points of Cole *et al.*<sup>(12)</sup> for BMI for children were used.

### Collection and analyses of blood samples for serum zinc

Non-fasting venous blood samples were drawn into trace-element-free evacuated tubes (Becton Dickinson, Frankton

Lakes, NJ, USA) from children in the sitting position, and the time of the blood collection was recorded. Blood was refrigerated immediately after collection<sup>(13)</sup> and then couriered chilled to a central laboratory for processing the next morning using appropriate trace-element-free techniques to avoid all sources of adventitious Zn contamination. After centrifugation and separation of the serum using trace-element-free techniques, the serum samples were stored at  $-80^{\circ}\text{C}$  until analysed. This protocol was developed after extensive pilot-testing which revealed that serum Zn concentrations analysed from blood samples using this protocol were not significantly different from those values obtained for serum from the same blood samples separated within 1 h of blood collection, provided the blood sample was kept cold at all times.

Serum Zn was analysed using flame atomic absorption spectrophotometry (Perkin Elmer AAnalyst 800; Perkin Elmer Corp., Norwalk, CT, USA) using a modified method of Smith *et al.*<sup>(14)</sup>. Serial replicates of a pooled serum sample and quality-control sera were used to check the precision and accuracy of the analytical method. The CV for Zn in the pooled serum was 3.9% ( $n = 82$ ). The value for the certified reference material, Bovine Serum Reference Material no. 1598 (National Institute of Standards and Technology), was 13.6 (SD 0.3)  $\mu\text{mol/l}$  (CV 2.5%,  $n = 21$ ) compared with the certified value of 13.6  $\mu\text{mol/l}$ . The presence of acute inflammation was assessed by serum C-reactive protein (CRP)  $>5\text{ mg/l}$ <sup>(15)</sup> using an immuno-turbidimetric assay with a Roche Hitachi 917 automated analyser (Roche Diagnostics, Indianapolis, IN, USA). Values for the manufacturer's controls for serum CRP fell within the certified ranges.

#### Assessment of inadequate intakes of zinc

Trained research assistants recorded all foods and beverages (including dietary supplements) consumed by the participant in the previous 24 h using a computer-assisted, multiple-pass 24 h diet recall interview in the home. Bar-code scanners were used to improve the accuracy of the product-name information for branded items. Recall data were entered into the computer at the time of the interviews using direct-capture programmes. Interviews were conducted to ensure that all days of the week were represented and included input from a parent or adult caregiver for the children  $<10$  years of age. Repeated 24 h diet recalls were conducted on a subsample of the children ( $n = 505$ ) so that nutrient intakes could be adjusted for within-person variability to obtain usual intake distributions. All of the 3275 children who participated in the survey completed a reliable 24 h recall, resulting in an overall analytic response of 100% for the diet recall component.

Intakes (as mg/d and per kg body weight (BW)) and major food sources of Zn (as percentage), but not phytate, were calculated from the 24 h recall data using the NZ

Food Composition Database compiled and maintained by Crop and Food Research Limited in NZ<sup>(16)</sup>. The prevalence of inadequate Zn intakes was calculated for each of the age-, sex- and ethnic-specific subgroups using the Estimated Average Requirement cut-point method based on the Australian and NZ estimated average requirements<sup>(17)</sup>, after adjusting for the distribution of observed intakes to partially remove the day-to-day variability in Zn intakes (within-person variation) using PC-SIDE (Department of Statistics, Iowa State University, Ames, IA, USA)<sup>(18)</sup>.

#### Data analysis

Anthropometric  $z$  scores were calculated from the US Center for Disease Control and Prevention 2000 growth reference data<sup>(19)</sup>. Multiple linear regression analyses were used to examine the independent predictors of serum Zn concentrations for each of the three ethnic groups. Sampling weights were used in all the analyses. Demographic characteristics of those participants who did and did not provide blood samples for serum Zn analysis were also examined. The explanatory variables included in the regression models were those that were known<sup>(1,4)</sup> or suspected<sup>(20,21)</sup> to be biologically important for Zn status. The variables investigated included sex, age category, SES, time of day of blood sampling (morning or afternoon), acute infection (serum CRP  $>5\text{ mg/l}$ ), season (summer or winter) and serum Se concentrations. For the purpose of this analysis, the Southern Hemisphere winter was defined as the months of May to October and summer as November to April. There was no evidence in the multiple regression models of multiple co-linearity among the independent variables.

Adjusted mean (95% CI) serum Zn concentrations were estimated for each ethnic group for three ages, stratified by sex, while accounting for survey weights and the variables in the regression model. In addition, the prevalence of serum Zn concentrations below the appropriate age-, sex-, and time of day-specific cut-offs were calculated by age category and sex for each ethnicity. Logistic regression was used to identify the predictors of low serum Zn concentrations.

Dietary variables were not included in the linear regression models because repeated 24 h diet recalls were only collected on a subsample of the survey participants. Hence, data on usual intakes at the individual level were not available<sup>(18)</sup>. Mean (95% CI) adjusted intakes of Zn (per day; per MJ; per kg BW) by the age categories specified for the Nutrient Reference Values for Australia and NZ<sup>(17)</sup>, and stratified by sex, were calculated and compared using the adjusted Wald test following regression. In addition, adjusted mean serum Se concentrations and adjusted dietary intakes of Zn, for those participants within each ethnic group with serum Zn concentrations below and above the appropriate

age-, sex-, and time of day-specific lower cut-offs were calculated and compared using the adjusted Wald test.

All *P* values were two-sided and were not adjusted for multiple testing. Statistically significant differences were indicated by  $P < 0.05$ . All the statistical analyses were performed using STATA, version 11.0 (Stata Corporation, College Station, TX, USA), accounting for the complex survey design.

## Results

Table 1 shows the proportions by age and sex in the three ethnicities in relation to the 2001 National School Roll. Of the 1927 children providing a blood sample, data for stature, serum Zn and dietary Zn intakes were available for 1753 children, yielding an overall response rate of 37.1% (1753 of the 4728 selected). There were no significant differences between the age, SES or BMI for those NZEO children who did or did not provide a blood sample for serum Zn analysis. However, the Māori and Pacific Island children for whom serum Zn concentrations were available tended to be 6 months younger and 3 months older, respectively, than their counterparts for whom no serum Zn values were available. Some data for serum Se concentrations ( $n$  132) and SES ( $n$  77) were also not available because of insufficient sample for serum Se analysis and lack of information on SES, respectively.

**Table 1.** Characteristics of the 2002 Children's Nutrition Survey serum sample relative to the 2001 New Zealand (NZ) school roll (Numbers and percentages)

	July 2001 NZ school roll ( $\times 1000$ )		2002 Serum sample	
	<i>n</i>	%	<i>n</i>	%
NZEO				
Boys	176	51	286	57
Girls	172	49	217	43
Māori				
Boys	57	49	266	51
Girls	59	51	256	49
Pacific				
Boys	21	51	334	46
Girls	21	49	394	54
NZEO				
Age (years)				
5–8	120	35	183	36
9–13	194	56	274	54
14–15	34	10	46	9
Māori				
Age (years)				
5–8	45	38	235	45
9–13	63	54	272	52
14–15	9	7	15	3
Pacific				
Age (years)				
5–8	16	38	260	36
9–13	22	52	385	53
14–15	4	10	83	11

NZEO, NZ European and other.

## Anthropometry

At ages 7, 11 and 14 years, children from the Pacific group had the highest positive weight-for-age *z* scores, height-for-age *z* scores (HAZ), and BMI *z* scores, and the highest prevalence of overweight and obesity, followed by the Māori; *z* scores for the NZEO group were the lowest. In the Māori and NZEO but not in the Pacific group, the *z* scores were lower among the older children, the difference being significant in some cases (Table 2). Sex differences in all the three ethnicities were small. About 2% of the children were stunted (i.e. HAZ  $< -2.0$ ) and/or underweight (weight-for-age *z* score  $< -2.0$ ).

Menarche (based on self-reports) had been reached by more girls in the Pacific (36.5%) and Māori (36.2%) groups than those in the NZEO (27.8%) group ( $P < 0.001$ ) (Table 2). No assessment of pubertal development was made in the boys.

## Predictors of serum zinc concentrations among the three ethnic groups

Significant predictors of serum Zn concentrations identified by regression analysis differed among the three ethnic groups (Table 3). In the NZEO group, sex, age and serum Se concentrations were all significant predictors. In contrast, for the Māori children, we were unable to identify any significant predictors, whereas for the Pacific children, sex, age, serum Se concentrations and season were significant. The interaction sex  $\times$  age was significant in the Pacific group. Note that the indicator variable for infection (CRP  $> 5.0$  mg/l) was not a significant predictor of serum Zn concentrations in any of the three ethnic-specific models.

Mean serum Zn concentrations for males and females by age for each of the three ethnic groups are shown in Table 4. An age-related increase in mean serum Zn concentrations was evident in all the three ethnicities and significant for the NZEO and Pacific groups (Table 3).

Sex differences in mean serum Zn concentrations were significant in the NZEO group; concentrations in girls were higher than boys ( $P = 0.012$ ). No sex differences were apparent in the Māori children (Table 4).

The time of day for the blood collection had an impact on mean serum Zn concentrations. Values tended to be higher in morning blood samples compared with the afternoon in all three ethnic groups. This difference was NS for each of the three ethnic groups (Table 3).

Seasonal differences were also apparent: serum Zn concentrations from winter blood samples were higher than the summer in all three ethnic groups, although this difference was only significant in the Pacific group ( $P = 0.016$ ) (Table 3) and for the overall sample ( $P > |t| = 0.049$ ; data not shown).

Acute inflammation, as indicated by elevated serum CRP levels, was generally absent; only 1.7% of the overall sample had CRP concentrations  $> 5$  mg/l.

**Table 2.** Anthropometric z-scores for three ethnic groups of New Zealand children at three ages (7.0, 11.0 and 14.0 years) (Adjusted mean values and 95 % confidence intervals)

	NZEO (n 503)		Māori (n 522)		Pacific (n 728)	
	Mean	95 % CI	Mean	95 % CI	Mean	95 % CI
Weight-for-age z score						
Age (years)						
7.0	0.41	0.22, 0.60	0.93	0.79, 1.06	1.28	1.15, 1.40
11.0	0.32	0.20, 0.43	0.73	0.62, 0.84	1.34	1.24, 1.44
14.0	0.24	0.05, 0.43	0.59	0.40, 0.77	1.39	1.18, 1.59
Significance of trend by age ( $P >  t $ )	0.278		0.010		0.453	
Significance ( $P > F$ ) < 0.001*						
Height-for-age z score						
Age (years)						
7.0	0.30	-0.02, 0.62	0.54	0.30, 0.78	0.83	0.65, 1.01
11.0	0.18	0.05, 0.31	0.43	0.32, 0.53	0.71	0.58, 0.83
14.0	0.09	-0.15, 0.33	0.34	0.15, 0.53	0.62	0.39, 0.84
Significance of trend by age ( $P >  t $ )	0.399		0.299		0.220	
Significance ( $P > F$ ) < 0.001*						
BMI-for-age z score						
Age (years)						
7.0	0.47	0.32, 0.62	0.95	0.82, 1.09	1.23	1.09, 1.37
11.0	0.35	0.26, 0.43	0.71	0.61, 0.82	1.28	1.21, 1.35
14.0	0.25	0.13, 0.38	0.54	0.37, 0.70	1.32	1.20, 1.44
Significance of trend by age ( $P >  t $ )	0.046		< 0.001		0.416	
Significance ( $P > F$ ) < 0.001*						
% With CRP > 5 mg/l ( $P < 0.001$ ) (%)*	1.2		2.9		2.4	
Menarche attained (% Females) ( $P < 0.001$ ) (%)*	27.8		36.2		36.5	
Low SES ( $P < 0.001$ ) (%)*	11.6		50.5		69.3	
Overweight ( $P < 0.001$ ) (%)*	19.0		22.8		33.4	
Obese ( $P < 0.001$ ) (%)*	4.3		14.6		30.0	

NZEO, New Zealand European and other; CRP, C-reactive protein; SES, socio-economic status.

\* Mean values were significantly different among ethnicities.

### Prevalence of zinc deficiency and predictors of low serum zinc among the three ethnic groups

The prevalence of Zn deficiency was highest in boys of the two younger age groups and ranged from 18 to 28% (Table 5), declining significantly with age in the NZEO group. The prevalence was significantly higher for boys compared with girls within each ethnicity and age category, although the number of subjects >14 years was small. The time of day for the blood collection and the season of the year were important factors in the prevalence of low serum Zn concentrations (Table 5), but neither obesity nor infection appeared to be significant factors (data not shown).

Predictors of low serum Zn concentrations based on the logistic regression analysis varied among the three ethnic groups (Table 6). For the NZEO group, sex, age and serum Se concentrations were significant predictors, whereas for the Māori group, season, sex and time of day of blood sampling were significant. For the Pacific group, season, sex, time of day of blood sampling and serum Se concentrations were significant.

### Intakes and major food sources of zinc among the three ethnic groups

For all the three ethnic groups, the oldest children (aged 14–15 years) had the highest mean intakes of Zn/d.

Further, boys had significantly higher mean Zn intakes/d than girls in all the three ethnic groups. Mean Zn intakes expressed per kg BW decreased significantly with age and were significantly higher for boys than girls in all the three ethnic groups (Table 7). Intakes of both insoluble and soluble dietary fibre for three ethnic groups were not significantly different ( $P > 0.05$ ). Dietary Zn supplements, taken by only 1.3% of the children, provided a negligible contribution to the overall total Zn intake (data not shown).

For the children overall, the major food sources of Zn were cereals (30%), meat/poultry/fish (23%), dairy products (15%) and fruits/vegetables (10%). However, ethnic differences in food sources of Zn were marked: dairy products provided significantly ( $P < 0.001$ ) different proportions of dietary Zn for Pacific (8.4%), Māori (12.9%) and NZEO (17.0%) children.

In general, the prevalence of inadequate Zn intakes was very low; <1% for both boys and girls 5–8 years and for boys aged 9–13 years in all the three ethnic groups. For girls aged 9–13 years, 2.3% of NZEO, 1.9% of Māori and 7.9% of the Pacific had inadequate intakes of Zn. There were too few children aged 14–15 years to calculate the prevalence of inadequate Zn intakes in the separate ethnic groups.

**Table 3.** Biological and technical factors associated with variations in serum zinc concentrations deduced from regression analysis with serum zinc as the dependent variable

(Coefficients and 95% confidence intervals)

	Coefficient	95% CI	( <i>P</i> >   <i>t</i>  )
NZEO ( <i>n</i> 395, <i>r</i> <sup>2</sup> 0.19)			
Sex	1.81	0.40, 3.22	0.012
Age	0.21	0.12, 0.30	<0.001
Sex × age	-0.12	-0.26, 0.01	0.075
Time of sampling	-0.60	-1.53, 0.33	0.202
Serum Se	1.95	0.60, 3.30	0.005
Infection (CRP >5.0 mg/l)	0.23	-0.67, 1.12	0.617
Season	0.41	-0.13, 0.95	0.135
Low socio-economic status	0.17	-0.46, 0.80	0.599
Māori ( <i>n</i> 379, <i>r</i> <sup>2</sup> 0.07)			
Sex	0.41	-0.85, 1.69	0.521
Age	0.12	-0.03, 0.27	0.106
Sex × age	-0.03	-0.17, 0.10	0.608
Time of sampling	0.32	-0.95, 0.31	0.319
Serum Se	0.59	-0.86, 2.04	0.422
Infection (CRP >5.0 mg/l)	-0.57	-1.32, 0.18	0.132
Season	0.30	-0.25, 0.85	0.285
Low socio-economic status	-0.43	-0.89, 0.02	0.061
Pacific ( <i>n</i> 589, <i>r</i> <sup>2</sup> 0.08)			
Sex	1.07	0.19, 1.97	0.018
Age	0.13	0.05, 0.21	0.002
Sex × age	-0.11	-0.20, -0.02	0.013
Time of sampling	-0.34	-0.91, 0.23	0.244
Serum Se	2.02	0.81, 3.23	0.001
Infection (CRP >5.0 mg/l)	0.40	-0.12, 0.92	0.129
Season	0.56	0.11, 1.01	0.016
Low socio-economic status	-0.32	-0.81, 0.18	0.207

NZEO, New Zealand European and other; CRP, C-reactive protein.

*Inter-relationships of dietary, anthropometric and biochemical indicators of zinc and selenium status*

In addition to the inter-relationships, apparent in the regression analysis (Tables 3 and 6), we also examined

the dietary and anthropometric indicators in relation to biochemical Zn status. Differences in mean Zn intakes/d for those children with low *v.* normal serum Zn concentrations were small and only significant (*P*=0.029) in the NZEO group where lower Zn intakes (mg/d) were associated with low Zn status. In contrast, mean Zn intakes/kg BW and major food sources of Zn were not significantly different for those children with low *v.* normal serum Zn concentrations in any of the three ethnicities (data not shown). Nevertheless, it is of interest that the proportion of dietary Zn (as %) from meat, poultry and fish tended to be lower in the children with low *v.* normal serum Zn concentrations in each of the three ethnic groups.

The only anthropometric indicator that was related to low serum Zn concentrations was the mean HAZ score. In the Pacific group, boys, but not the girls with low serum Zn concentrations, had a significantly lower mean HAZ score than their counterparts with normal serum Zn concentrations (*P* for interaction=0.007). There was a tendency for the same relationship in Māori (*P* for interaction=0.096). No comparable relationship was observed in the NZEO group. No relationship was observed between mean BMI *z* scores in the boys or girls and low serum Zn concentrations in any of the three ethnic groups.

Mean serum Se concentrations for the NZEO and Pacific children (but not the Māori) with low serum Zn concentrations were significantly lower than those for their counterparts with normal serum Zn concentrations (NZEO: 0.88 *v.* 0.97 μmol/l; *P*=0.022 and Pacific: 1.00 *v.* 1.04 μmol/l; *P*=0.006) – a relationship supported by the regression analysis (Tables 3 and 6).

**Table 4.** Serum zinc concentrations (μmol/l)\* of three ethnic groups of New Zealand children at three ages (7.0, 11.0 and 14 years), sex, time of day of blood sampling (morning or afternoon)† and season (winter or summer)† (Adjusted means and 95% confidence intervals)

	NZEO ( <i>n</i> 395)		Māori ( <i>n</i> 379)		Pacific ( <i>n</i> 589)	
	Mean	95% CI	Mean	95% CI	Mean	95% CI
Age (years)						
7.0						
Male	11.0	10.5, 11.4	11.5	11.0, 11.9	11.0	10.6, 11.4
Female	11.9	11.4, 12.4	11.6	11.2, 12.1	11.3	10.9, 11.8
11.0						
Male	11.8	11.5, 12.2	12.0	11.5, 12.4	11.5	11.2, 11.9
Female	12.3	11.9, 12.6	12.0	11.5, 12.5	11.4	11.0, 11.8
14.0						
Male	12.5	12.0, 12.9	12.3	11.5, 13.1	11.9	11.4, 12.4
Female	12.6	12.0, 13.1	12.2	11.4, 13.1	11.5	11.0, 11.9
Time of day						
Morning	13.1	11.1, 15.1	12.6	11.1, 14.2	12.3	10.9, 13.6
Afternoon	12.5	11.4, 13.6	12.3	11.3, 13.3	11.9	11.1, 12.8
Season						
Winter	13.3	11.4, 15.3	12.8	11.1, 14.4	12.6	11.1, 14.0
Summer	12.9	10.8, 15.0	12.5	10.9, 14.1	12.0	10.8, 13.2

NZEO, New Zealand European and other.

\*Data by age and sex account for survey design and the other variables in the regression models (Table 3).

†Data for time of day and season are for age 11 years.

**Table 5.** Prevalence\* of zinc deficiency based on low serum zinc concentrations by age and sex, time of sampling and season (Mean values and 95 % confidence intervals)

	NZEO (n 469)		Māori (n 481)		Pacific (n 712)	
	Mean	95 % CI	Mean	95 % CI	Mean	95 % CI
Age group (years)						
5–8						
Male	26	13, 40	18	9, 26	27	19, 35
Female	13	5, 21	13	6, 21	15	5, 24
9–13						
Male	19	10, 28	28	20, 36	25	8, 41
Female	8	3, 14	8	3, 12	18	7, 30
14–15						
Male	7	–4, 19	8	–9, 26	15	0, 29
Female	None		None		13	–2, 27
All ages	15	9, 21	16	12, 20	21	11, 30
Significance of trend by age ( $P >  t $ )	0.008		0.299		0.799	
Significance of sex difference ( $P >  t $ )	<0.001		0.029		0.014	
Significance of differences among ethnicities ( $P > F$ ) = 0.009						
Time of day						
Morning	16	9, 23	17	13, 22	26	19, 34
Afternoon	10	2, 17	9	0, 19	10	0, 21
Significance of morning/afternoon ( $P >  t $ )	0.130		0.001		0.042	
Season						
Winter	12	6, 18	10	6, 15	14	5, 22
Summer	19	7, 30	24	18, 29	32	23, 41
Significance of season ( $P >  t $ )	0.406		0.003		0.017	

NZEO, New Zealand European and other.

\* Adjusted for survey weights.

## Discussion

Serum Zn concentrations are now the recommended biomarker of population Zn status<sup>(5,22)</sup>, even though levels are influenced by several factors independent of Zn status, including time of day of blood sampling, fasting status and infection. Here, we report for the first time, two additional variables – serum Se and season – as predictors of serum Zn concentrations.

Serum Zn concentrations for the morning blood samples were higher than afternoon samples, as noted by others<sup>(1,4,23)</sup>. Concentrations are generally also higher after a recent meal<sup>(23)</sup>. However, we collected only non-fasting blood samples, without information on the time of the most recent meal, to minimise respondent burden. Hence, we were unable to examine the impact of fasting status. Meal-induced changes may account for some of

the unexplained variance in serum Zn concentrations. Very few children (1.7%) had elevated serum CRP levels, probably because those with an acute infection on the blood-collection day were absent from school and thus not sampled. Hence, failure to demonstrate an inverse relationship between elevated concentrations of serum CRP and low serum Zn is not surprising<sup>(1,4)</sup>.

Age and sex influence serum Zn concentrations<sup>(1)</sup>. Here, mean serum Zn concentrations for boys and girls increased with increasing age across the three ethnicities, a trend also observed in the US<sup>(1)</sup> and Mexico<sup>(3)</sup> national surveys and elsewhere<sup>(7)</sup>. A parallel fall in the prevalence of low serum Zn concentrations was also observed (Table 5). The NZEO boys had significantly lower mean serum Zn concentrations than girls (Table 4), and in all three ethnicities, the prevalence of low serum Zn concentrations is higher in males than in females (Table 5). In general, we conclude that it is

**Table 6.** Logistic regression analysis\*† for the prevalence of low serum zinc concentrations below the international cut-offs (Odds ratios and 95 % confidence intervals)

	NZEO (n 389)			Māori (n 379)			Pacific (n 712)		
	OR	95 % CI	$P >  t $	OR	95 % CI	$P >  t $	OR	95 % CI	$P >  t $
Blood sample collected in summer	1.64	0.63, 4.26	0.309	2.52	1.38, 4.57	0.003	2.51	1.17, 5.35	0.018
Sex (male)	3.13	1.47, 6.66	0.003	1.98	1.04, 3.79	0.039	1.71	1.15, 2.54	0.008
Age (years)	0.85	0.74, 0.96	0.013	0.98	0.87, 1.09	0.662	1.01	0.91, 1.13	0.819
Blood sample collected in the morning	3.62	0.64, 20.4	0.143	6.06	2.07, 17.70	0.001	3.02	1.04, 8.77	0.042
Serum Se ( $\mu\text{mol}$ )	0.037	0.003, 0.47	0.012	1.18	0.20, 6.81	0.851	0.16	0.03, 0.80	0.026
Low socio-economic status	0.42	0.12, 1.48	0.175	1.79	0.92, 3.47	0.086	1.27	0.60, 2.69	0.530

NZEO, New Zealand European and other.

\* Analysed separately by ethnicity.

† Adjusted for survey weights.



**Table 7.** Dietary zinc intakes expressed (mg/d) and mg/kg body weight (BW) of three ethnic groups of New Zealand children by age category and stratified by sex

(Mean values and 95 % confidence intervals)\*

	NZEO (n 503)		Māori (n 522)		Pacific (n 728)	
	Mean	95 % CI	Mean	95 % CI	Mean	95 % CI
<b>Zn intake (mg/d)</b>						
Age group (years)						
5–8						
Male	10.3	9.2, 11.4	10.1	9.4, 10.8	9.7	9.1, 10.4
Female	7.6	6.6, 8.6	8.7	7.8, 9.5	8.4	7.8, 9.1
9–13						
Male	11.7	10.5, 12.9	10.8	10.0, 11.6	11.1	10.2, 11.9
Female	9.0	8.3, 9.7	9.3	8.4, 10.3	9.8	9.1, 10.4
14–15						
Male	14.1	12.1, 16.2	12.2	8.4, 16.0	14.6	12.9, 16.3
Female	11.4	9.5, 13.4	10.7	7.4, 14.1	13.3	11.8, 14.8
Significance of positive trend with age ( $P >  t $ )	< 0.001		0.066		< 0.001	
Overall, significance of sex ( $P >  t $ )	< 0.001		0.007		0.001	
Significance of differences among ethnicities ( $P > F$ ) = 0.647						
<b>Zn intake (mg/kg BW)</b>						
Age group (years)						
5–8						
Male	0.38	0.34, 0.41	0.37	0.34, 0.39	0.32	0.30, 0.34
Female	0.31	0.28, 0.34	0.32	0.30, 0.35	0.29	0.27, 0.32
9–13						
Male	0.28	0.26, 0.30	0.24	0.22, 0.26	0.21	0.19, 0.23
Female	0.22	0.20, 0.24	0.20	0.18, 0.22	0.19	0.17, 0.20
14–15						
Male	0.25	0.21, 0.29	0.23	0.16, 0.30	0.20	0.18, 0.23
Female	0.19	0.15, 0.23	0.18	0.12, 0.25	0.18	0.15, 0.20
Significance of negative trend with age ( $P >  t $ )	< 0.001		< 0.001		< 0.001	
Overall, significance of sex ( $P >  t $ )	< 0.001		0.003		0.003	
Significance of differences among ethnicities ( $P > F$ ) < 0.001						

NZEO, New Zealand European and other.

\* Adjusted for survey weights.

the younger male children who are particularly at risk of suboptimal Zn status. Lower serum Zn concentrations in boys have been reported elsewhere<sup>(24,25)</sup>. Indeed, in some Zn-supplementation trials, boys have shown a greater response in linear growth than girls<sup>(25–27)</sup>; possibly, their higher growth rates and greater proportion of muscle/kg BW<sup>(4)</sup> generate higher Zn requirements. Other postulated mechanisms involve sex-related changes in growth hormone and testosterone concentrations which increase the metabolic requirements for Zn<sup>(28)</sup>.

Serum Se concentrations were a strong predictor of serum Zn in the NZEO and Pacific children, but not in the Māori (Table 3). The reason for this inconsistency is uncertain. It may be related to the greater range in serum Se concentrations in the Pacific (0.44–1.56  $\mu\text{mol/l}$ ) and NZEO (0.55–1.41  $\mu\text{mol/l}$ ) ethnicities compared with the Māori (0.55–1.41  $\mu\text{mol/l}$ ). Other studies in NZ<sup>(29)</sup> and elsewhere<sup>(20)</sup> have reported positive associations between serum Se and serum Zn concentrations. Selenoproteins, specifically glutathione peroxidases, have the potential to have an impact on Zn status through their role in regulating the delivery of Zn from metallothionein to certain Zn enzymes, specifically Cu, Zn superoxide dismutase<sup>(30)</sup>. According to Thomson *et al.*<sup>(8)</sup>, serum Se concentrations of many of these NZ children are unlikely to be adequate

for maximal glutathione peroxidase activity because this enzyme is the first selenoprotein to decline in Se deficiency. It is possible therefore, that low glutathione peroxidase activity induces low serum Zn concentrations and as a consequence, serum Zn and serum Se concentrations become positively correlated, as reported here among the Pacific and NZEO groups.

Serum Zn concentrations were higher in the winter than in the summer across all ethnic groups (Table 4), a pattern noted previously for hair Zn levels in children<sup>(21,31)</sup>. Such seasonal trends in Zn status may be associated with the well-documented seasonal changes in linear growth<sup>(32)</sup>, which may result in depletion of body Zn reserves in the spring/summer, as a consequence of rapid growth.

The NZ children studied here had mean adjusted serum Zn values, when classified by sex and age, which were comparable with those reported in US National Health and Nutrition Examination Survey II<sup>(1)</sup>. Much higher serum Zn values have been reported<sup>(7,33,34)</sup>, but not all of these studies followed the latest recommended protocols for serum Zn analysis<sup>(4,13)</sup>.

In these NZ children, risk of Zn deficiency, based on low serum Zn concentrations, varied significantly by ethnicity. Pacific children had the highest risk (21%), with a prevalence indicative of public health concern (i.e. > 20%)<sup>(5)</sup>,

followed by Māori children (16%), and NZEO children (15%) had the lowest risk. We believe that these differences are probably, at least in part, due to an effect of ethnicity. Pacific and Māori children undergo puberty earlier and are taller for chronological age than Europeans<sup>(35)</sup>, trends also observed here (Table 2). As a result, their Zn requirements are likely to be higher than that of their European counterparts. Pacific children also have a greater lean body mass compared with European children of similar height<sup>(36)</sup> which, because of the higher Zn content of muscle compared with fat<sup>(4)</sup>, may further exacerbate the risk of Zn deficiency among this ethnic group.

It is noteworthy that data for all the three ethnicities showed a higher risk of Zn deficiency in morning *v.* afternoon blood samples (Table 5). This aberration may be related to uncertainties in the morning and afternoon serum Zn cut-offs<sup>(4)</sup>.

The present study provides some evidence of functional disturbances related to suboptimal Zn status. In the Pacific group, the mean HAZ score of the boys with low serum Zn concentrations was significantly lower than those with normal serum Zn concentrations, again emphasising the higher risk of Zn deficiency in male children. Observational<sup>(37,38)</sup> and Zn supplementation<sup>(39)</sup> trials have demonstrated comparable positive relationships between serum Zn and linear growth. No relationship was observed with BMI *z* scores. Morbidity data were not collected, so whether the lower Zn status of the Pacific children was associated with a higher prevalence of infectious illnesses is unknown. However, NZ Pacific children are known to have the highest hospitalisation rates for pneumonia, followed by Māori; NZEO children have the lowest<sup>(40)</sup>.

Interestingly, Zn intakes were lowest in the Pacific group (Table 7) when expressed in terms of mg/kg BW and may reflect differences in food selection patterns associated with ethnicity, real differences in energy intakes or bias, resulting from under- or over-reporting<sup>(33)</sup>, although the latter was not assessed<sup>(6)</sup>. The significant decrease in intake with age in all the three ethnic groups may reflect the existence of a non-linear relationship between Zn intake and BW.

Overall, in the NZ CNS02 survey, Pacific girls aged 9–13 years had the highest risk of inadequate intakes of Zn, although the prevalence was very low among all the children. However, the dietary requirements for Zn may be higher for the larger Pacific and, to a lesser extent, Māori children. Hence, the prevalence of inadequate intakes may be underestimated in these two ethnic groups, thus contributing, at least in part, to the lack of concordance between our predicted prevalence for risk of Zn deficiency based on dietary and biochemical indicators. Other contributing factors include the wide array of confounding factors influencing serum Zn concentrations, some identified for the first time in our NZ survey, and most importantly, uncertainties in the cut-offs for children used to define low serum Zn status and inadequate Zn intakes<sup>(41)</sup>.

Certainly, in adults, the magnitude of the inhibitory effect of dietary phytate on Zn absorption is said to be much greater than previously recognised. Whether this is also the case for young children is less certain<sup>(42)</sup>.

Despite the apparent greater risk of population Zn deficiency in the Pacific children, very few were classified as stunted. Indeed, their mean HAZ scores for all three age categories tended to be higher than those for the Māori and NZEO groups. However, whether the US Center for Disease Control and Prevention 2000 growth reference data<sup>(19)</sup> are appropriate for Pacific and Māori children, who are taller for chronological age than Europeans<sup>(36)</sup>, is questionable.

Some of the study limitations derive from the intentional over-sampling of the Māori, and particularly the Pacific group to permit these minority groups to be better characterised in the NZ CSN02. For this reason, we analysed the data for the three ethnicities separately, applying nationally based survey weights for age, sex and non-response for each ethnicity. The age- and sex-related associations were less marked among the Māori compared with the Pacific and NZEO ethnicities, probably at least in part, because of the very small number of Māori aged 14–15 years (*i.e.* *n* 15) for whom serum Zn values were available compared with the numbers in the other two groups. A second limitation relates to requesting serum samples only from children in urban and semi-urban areas. Specific national weights for this sampled fraction of the NZ CSN02 were used, and urban children make up more than approximately 90% of NZ children. Nevertheless, the absence of serum Zn values from the rural school children, as well as the urban and semi-urban children who refused to provide a blood sample, limited the representativeness of our data. Finally, our data are observational, and therefore the present results do not imply causality.

In summary, notwithstanding the limitations, the present results indicate that, of the three ethnicities, the Pacific group had the highest prevalence of low serum Zn concentrations (21%), considered indicative of population Zn deficiency, followed by Māori children (16%); NZEO children had the lowest prevalence (15%). Suboptimal Zn status among the Pacific children may have been exacerbated by their greater stature and lean body mass, and thus higher requirements for Zn than the NZEO children, coupled with a lower Zn intake, when expressed per kg BW. Consequently, the lack of concordance between risk of population Zn deficiency based on the prevalence of inadequate Zn intakes and low serum Zn concentrations may be partly associated with an underestimate of the prevalence of inadequate intakes of Zn in the larger Pacific and Māori children, together with the multiple factors influencing serum Zn concentrations. The relative importance of these various factors varied with ethnicity, but age, sex and time of the sample collection along with two previously unreported variables – serum Se and season – were significant determinants of serum Zn concentrations

in one or more ethnic groups, and the risk of suboptimal Zn status appears to be particularly high among younger male children. Our findings highlight the necessity for more research to better define the cut-offs for both dietary and biochemical indicators used to define the risk of population Zn deficiency.

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