Public Health Nutrition: 20(1), 102–111 doi:10.1017/S1368980016001956

The association between diet quality and subclinical inflammation among children aged 6–18 years in the Eastern Cape, South Africa

Wilna Oldewage-Theron[1,2,*] and Rozanne Kruger[3]

[1]Centre of Sustainable Livelihoods, Vaal University of Technology, Private Bag X021, Vanderbijlpark 1900, South Africa: [2]Department of Nutritional Sciences, College of Human Sciences, Texas Tech University, 1301 Akron Avenue, Human Sciences 608, Lubbock, TX 79409, USA: [3]School of Food and Nutrition, MIFST, College of Health, Massey University, Auckland, New Zealand

Submitted 21 August 2015: Final revision received 26 April 2016: Accepted 14 June 2016: First published online 2 August 2016

Abstract

Objective: The study aimed to investigate, for the first time, the association between diet quality (food variety and dietary diversity), intakes of anti-inflammatory nutrients and food groups, and subclinical inflammation as assessed by categories of high-sensitivity C-reactive protein (hs-CRP).

Design: Cross-sectional study.

Setting: Resource-poor, rural children in the Eastern Cape, South Africa.

Subjects: A sample size formula determined a representative sample of 235. Five schools were purposively selected and cluster sampling used to select 240 participants. Measurements included 24 h recall and dietary diversity questionnaires, anthropometric and biochemical measurements.

Results: The sample consisted of 50·4 % (*n* 118) girls and 49·6 % (*n* 116) boys. No obesity was found, but overweight was prevalent in 4·2 % of the children. The hs-CRP concentration (median (25th, 75th percentile)) of the low, medium and high risk inflammatory categories was 0·6 (0·4, 0·7), 1·6 (1·2, 2·2) and 4·2 (3·4, 6·4) mg/l, respectively. Body composition parameters did not differ between hs-CRP groups. Most of the anti-inflammatory nutrient intakes (dietary Fe, Zn, Mg, vitamin C, folate, linolenic acid, linoleic acid, MUFA and PUFA) differed significantly between the hs-CRP groups, with intakes increasing from low to high hs-CRP groups, with similar results for linolenic acid ($P = 0{\cdot}022$) intake. No significant relationships between hs-CRP and any of the food groups could be established, but significant relationships were established between hs-CRP levels and the high density of living arrangements and unhygienic ablution facilities.

Conclusions: Although no link could be established between overnutrition and hs-CRP levels, an association was found between hs-CRP and dietary quality, as well as socio-economic status.

Keywords
High-sensitivity C-reactive protein
Subclinical inflammation
Children
South Africa

A well-established link exists between subclinical inflammation, as measured by C-reactive protein (CRP), and CVD risk[1]. In addition, high CRP levels have been correlated with metabolic syndrome and stroke, and can even predict the future development of type 2 diabetes mellitus[1–3]. Obesity is also well known for dysregulating various metabolic pathways, including low-grade inflammation, which may be revealed in chronically high pro-inflammatory biomarkers like CRP[4]. However, other factors have also been shown to have an impact on CRP levels, including poverty[3], genetic variation[5] and dietary behaviours such as food and nutrient intakes, particularly fibre, fruit and vegetable intakes[6]. The burden of nutrition-related non-communicable diseases (NCD) in South Africa is high[7] and is predicted to increase, especially in rural communities[8]. Overweight and obesity, an important risk factor for NCD, is increasing worldwide, as well as in South Africa. Obesity results in dysregulation of the endocrine system, causing chronic low-grade inflammation that can be assessed by pro-inflammatory biomarkers, of which high-sensitivity CRP (hs-CRP) is the one most commonly used[4]. This inflammatory state is a strong predictor of NCD risk[3]. Early detection, especially during childhood, is one of the strategies employed by the national South African strategic plan to prevent and address the burden of NCD[7].

**Corresponding author:* Email Wilhelmina.theron@ttu.edu

The development of hs-CRP assays allowed evaluation of elevated, but not acute, CRP levels when assessing future disease risk. These inflammatory markers may even be pro-atherogenic in childhood and thus important as early predictors of adult chronic disease risk[3–6]. High CRP levels in asymptomatic individuals are important when considering potential disease risk. It is thus important to investigate the state of subclinical inflammation that occurs when CRP levels are slightly elevated over a prolonged period without a systemic response[1]. Levels of hs-CRP have been classified, using cut-offs for low, medium and high risk of future CVD, corresponding to approximate tertiles in adults of <1·0, 1·0–3·0 and >3·0 mg/l, respectively[1,6,9]. Lower levels of hs-CRP appear to have a predictive protective effect for future CVD events[2].

Dietary factors have also been investigated in relation to CRP levels in adults, where CRP levels were lower in those with high grain, fruit and vegetable intakes, thus reflecting Mediterranean-style diets. In children, there are fewer studies; several show effects similar to those for adults and one study showed a positive association between high CRP level and fat intake[6]. Several studies have shown that healthy or health-protecting foods and nutrients with anti-inflammatory qualities, such as high intakes of grains and fibre[10–12], vegetables[12,13], fruit[12], dairy, EPA[14], linolenic acid[14], PUFA[14] and MUFA, Zn[15], Fe[16], Mg[17,18], vitamin C[19] and folate[9], are inversely related to CRP concentrations. These findings were consolidated in reviews by Lazarhou and Philippou and Shivappa *et al.*, who labelled these nutrients and foods anti-inflammatory diet components[9,20]. Both these reviews also reported that CRP concentrations were significantly related to individual 'unhealthy' nutrient and food intakes, such as high intakes of total fat, percentage of energy as fat, plant oils and SFA[10,13,21], and high consumption of foods such as fried foods, fried potatoes, sweets, chocolates, desserts, potato chips[13], delicatessen meats and soft drinks[22]. These foods were categorised as having pro-inflammatory qualities[9,20]. Furthermore, the additive effect of several unhealthy foods, as listed above, estimated by using a dietary index, showed a positive association with CRP concentration[9].

Evidence linking hs-CRP and diet is scarce, especially in children. Recent data support protection against chronic low-grade inflammation through healthy dietary practices during childhood[9]. Therefore, the aim of the present study was to investigate the associations of various components of diet quality (including dietary diversity assessments and anti-inflammatory nutrient and food intakes) with subclinical inflammation (the prevalence of low, moderate and severe inflammation categories using serum hs-CRP levels) in resource-poor, rural children between the ages of 6 and 18 years living in the Eastern Cape Province of South Africa.

Methods

Sampling

A sample size calculation[23] was used to determine the sample size for a 95 % confidence level and 6·25 CI, based on the total number of schoolchildren (age 6–18 years; *n* 5250) in public schools in the study region. Five schools were purposively selected by the Department of Basic Education, based on the criteria of having low income (<ZAR2000 per household per month) and being predominantly Xhosa-speaking. A cluster sampling method, based on gender, age and school distribution, was used to select the 235 participants needed for statistical representation. A total of 240 children were selected; a complete data set was obtained for 234 children and used for analyses and reporting of the results.

Data collection

All questionnaires were completed in a one-to-one interview with the assistance of trained fieldworkers. A validated socio-economic questionnaire[24] was used, which included questions to elicit household size, the age and education level of the child caregivers/legal guardians of the households, as well as household composition, monthly income and basic living conditions, such as water and sewerage facilities and the structure of the dwelling.

A four-stage, multiple-pass interviewing procedure[25] was used for the 24 h recall questionnaire data collection to ensure that 24 h data were correctly measured. Based on the fact that dietary intake measurements are not reliable, two 24 h recall questionnaires (one weekday and one weekend day) were completed for each respondent. An adapted dietary diversity questionnaire[26] was used to collect data on dietary diversity indices. The dietary diversity questionnaire was a printed list of foods categorised according to the nine nutritious food groups recommended by the FAO[27].

A registered dietitian (South Africa) and public health nutritionist (USA) were responsible for measuring weight and height according to standardised methods. Two measurements were taken, which were not to vary by more than 0·1 kg and 5 mm for weight and height, respectively. The average of the two measurements was used in case of any variation[28].

Using a Vacutainer needle, with minimal use of tourniquets, a nursing sister and a haematologist drew venous blood samples from participants after they had been sitting quietly for 15 min. Five millilitres of blood was collected in a silicone-coated tube for preparation of serum for the analysis of hs-CRP. The blood was placed on ice until separation within 2 h of blood collection. Serum was harvested by low-speed centrifugation at 4°C and aliquoted into individual tubes. Serum was stored at −80°C until analyses. A colorimetric method was used for analysis on the Konelab 20i analyser.

Data analyses

A complete database existed for 234 respondents, including 118 girls and 116 boys. The statistical software package IBM SPSS Statistics Version 22.0 was used for all statistical analyses and $P < 0{\cdot}05$ was considered significant for all statistical tests. Linearity regression was used to test all continuous variables for normality. Most were not normally distributed; thus medians and 25th percentiles, 75th percentiles (P25, P75) instead of means and standard deviations were calculated. The socio-economic data were analysed for descriptive statistics (frequencies and percentages, as well as medians and P25, P75). Anthropometric data were analysed using the WHO AnthroPlus software to calculate underweight (weight-for-age), stunting (height-for-age) and thinness/wasting (BMI-for-age). Underweight was defined as weight-for-age *Z*-score <−2 (severe underweight, *Z*-score <−3), stunting was defined as height-for-age *Z*-score <−2 (severe stunting, *Z*-score <−3), thinness as BMI-for-age *Z*-score <−2 (severe thinness, *Z*-score <−3) and overweight as BMI-for-age *Z*-score >+2 but ≤3 (obesity, *Z*-score > +3)[29]. The 24 h recall data were captured and analysed under the supervision of a registered nutritionist, using the FoodFinder program version 3, a dietary analysis program developed by the Medical Research Council and based on the South African Food Consumption Tables[30]. Nutrient intakes were analysed and medians compared with the Dietary Reference Intakes for age groups 4–8, 9–13 and 14–18 years[31–35]. Frequencies were used to determine the percentage of participants with nutrient intakes below 100 % of the Estimated Average Requirements. Only total energy intake and the anti-inflammatory nutrients[9] are reported in the results. The 24 h recall data were further analysed to calculate the median intakes of the inflammatory food components (fried foods, sweets and chocolates, confectionery, processed meats and soft drinks)[9].

The dietary diversity questionnaire data were used to determine the Food Variety Score (FVS) and the Food Group Diversity Score (FGDS). The FVS consisted of a simple count of single foods within the nine nutritional food groups[27,36,37]. Matla[26] described the cut-off points for a low, medium and high FGDS and FVS as follows: 0–3 food groups and <30 individual foods, 4–5 food groups and 30–60 individual foods, and 6–9 food groups and >60 individual foods, respectively. The dietary diversity questionnaire was statistically analysed for descriptive statistics (frequencies, medians and P25, P75). Medians and P25, P75 were calculated according to hs-CRP category before being compared with the normal range. The percentage of respondents with abnormal values was also calculated. Pearson (nominal parameters) and Spearman (categorical parameters) correlations were used to determine significant relationships between variables; however, only statistically significant relationships are reported in the 'Results' section. ANOVA with the correction of the Bartlett's test for equal variances was used to compare the medians within different hs-CRP categories at a significance level of $P \leq 0{\cdot}05$. MANOVA was used to control for energy and BMI-for-age *Z*-score to determine the significance of the relationships between hs-CRP and the various significantly correlated dietary intake variables. According to Pillai's Trace the model was fit for the multivariate analyses ($P = 0{\cdot}000$), whereby the corrected model confirmed R^2 ranging from 86 to 94 %.

Results

Socio-economic results

The sample consisted of 50·4 % (*n* 118) girls and 49·6 % (*n* 116) boys. The mean age of the children was 7·0 (SD 0·8) years in the group of 4–8-year-olds, 11·0 (SD 1·4) years in the group of 9–13-year-olds and 16·0 (SD 1·4) years in the group of 14–18-year-olds. The mean age of the child caregivers/legal guardians was 53·8 (SD 16·1) years, ranging from 21 to 103 years. The majority were single-headed households (62·7 %), with 36·9 % of those heading the households being single, 24·4 % widowed and 1·4 % divorced. Only 19·3 % of the child caregivers/legal guardians had no formal education, while 46·8 % had primary, 30·3 %, secondary and 3·7 % had tertiary education.

The average household size was 5·3 people, ranging from 2 to 10. Hygiene seemed to be compromised as 60·3 % did not have running potable water at the house and needed to fetch water from elsewhere. Furthermore, waste removal services did not exist for 94·6 % of the households. The majority had a pit latrine (57·1 %) and 38·4 % had no toilet facilities. Only 7·7 and 11·4 % of the child caregivers/legal guardians and their spouses were employed, respectively, with 80·7 % having a household income of less than ZAR2000 per month. This amounts to ZAR12·58 per person per day ($US 1·00 per person per day), which is less than the cut-off point for people living in poverty according to the United Nations Development Programme[38].

Anthropometric results

Both gender groups showed suboptimal results when compared with the WHO weight-for-age growth standard for the same gender and age groups. No boys were underweight whereas 8·3 % of the girls were. Underweight is usually the result of acute insufficient food and nutrient intake[39]. No children were severely underweight. Stunting, which indicates chronic insufficient food and nutrient intake and/or frequent infection[39], was prevalent in both genders (3·8 %), affecting more girls (5·6 %) than boys (2·3 %). Furthermore, stunting was more pronounced among older children (10–19 years). No children were severely stunted. The BMI-for-age results showed a prevalence of 1·7 % of severe wasting for the total group; 2·5 % of the girls were wasted compared with 4·3 % of the boys. Risk of overweight was 14·0 % in all the children,

and 10·0 % in the girls compared with 18·1 % in the boys. The prevalence of overweight was 4·2 % for all the children; however, 4·3 % of the boys were overweight compared with 4·2 % of the girls. None of the children were obese.

Biochemical results

The median hs-CRP level was 2·3 mg/l for the total group of children. The children were grouped in subcategories for low (<1·0 mg/l; *n* 73, 31·5 %), medium (1·0–3·0 mg/l; *n* 115, 49·5 %) and high (>3·0 mg/l; *n* 44, 19·0 %) hs-CRP levels[2] (see Table 1).

The hs-CRP concentration (median (P25, P75)) of the low, medium and high categories was 0·6 (0·4, 0·7), 1·6 (1·2, 2·2) and 4·2 (3·4, 6·4) mg/l, respectively. It was clear from the results that there was no difference in body composition parameters between the hs-CRP groups; however, the BMI-for-age *Z*-score of the girls and boys differed significantly ($P < 0·025$).

Dietary intake results

The nutrient intake analysis indicated deficient intakes for the total energy, folate and vitamin C for the group of children aged 6–8 years compared with the Estimated Average Requirements and WHO guidelines, respectively. Despite sufficient median intakes of Fe, Mg and Zn, 46·4, 23·1 and 37·5 % of the children in the sample consumed less than 100 % of the Estimated Average Requirement, respectively (see Table 2). The same trend was observed for the children aged 9–13 years. In the group aged 14–18 years, low median intakes were observed for total energy and all of the anti-inflammatory nutrients.

No significant differences were observed in the dietary fat intake variables between the groups, except for linolenic acid, where the children aged 14–18 years had a significantly ($P = 0·022$) lower intake than those aged 6–13 years. Furthermore, significantly different intakes were observed between the different age groups for total energy ($P = 0·001$), Fe ($P = 0·011$), Mg ($P = 0·004$) and folate ($P = 0·012$). The intakes of Fe, Mg and Zn increased with age. The 9–13-year-old children had higher folate and vitamin C intakes than either the 6–8- or 14–18-year-old group. Furthermore, the percentage of children with inadequate intakes of Fe, Mg, Zn, folate and vitamin C increased progressively with age. The per capita median intake of fried foods was 36·6 g, sweets and chocolates 24·9 g, confectionery 7·4 g, processed meats 15·7 g and soft drinks, 166·0 ml/d.

Dietary diversity results

The total number of food items consumed by the children was 54 for the period of 7 d, showing a medium food variety. However, the number of individual foods mostly consumed by an individual ranged between 17 and 29. This was confirmed by the median FVS of 22·9, which indicates that the participants had a low FVS[26], with a minimum intake of 1 and a maximum of 54 individual food items for the 7 d period.

When assessing food group diversity, the cereal, flesh, other vegetables and fruit groups reflected the most variety, with 15, 10, 9 and 9 different food items in each group, respectively. The median FGDS (dietary diversity score) of 8·0 indicated a high dietary diversity[26]. The majority of the children (94·4 %) consumed 6–9 groups (high FGDS) and 5·6 % consumed 4–5 groups (medium FGDS).

Intakes of all the anti-inflammatory nutrients (namely, dietary Fe, Mg, Zn, vitamin C, folate, MUFA, PUFA, linoleic acid, linolenic acid) differed significantly between the hs-CRP groups, except Mg. The anti-inflammatory nutrient intakes increased progressively from the low to the high hs-CRP group, with similar results for linolenic acid ($P = 0·022$) intake. Interestingly, these nutrients have all been categorised by Lazarhou and Philippou as health-protecting[9]; however, intakes of all these nutrients appeared to increase from the low hs-CRP to the high hs-CRP category, indicating that higher intakes were

Table 1 Characteristics of children aged 6–18 years (*n* 232), by category of high-sensitivity C-reactive protein (hs-CRP) level, Eastern Cape, South Africa

	hs-CRP category							
	Low (<1·0 mg/l)		Medium (1·0–3·0 mg/l)		High (>3·0 mg/l)			
Parameter	Median or *n*	P25, P75 or %	Median or *n*	P25, P75 or %	Median or *n*	P25, P75 or %	Significant differences between groups, two-sided *P* value	Significant differences between genders, two-sided *P* value
hs-CRP (mg/l)	0·6	0·4, 0·7	1·6	1·2, 2·2	4·2	3·4, 6·4	0·000*	0·374
Age (years)	13·0	10·0, 16·0	12·0	8·0, 16·0	12·0	8·0, 15·5	0·404	0·516
Gender							0·725	
Boys (*n* and %)	38	33·6	56	49·6	19	16·8		
Girls (*n* and %)	35	29·4	59	49·6	25	21·0		
Height (m)	1·5	1·4, 1·6	1·5	1·3, 1·6	1·5	1·3, 1·6	0·344	0·534
Height-for-age *Z*-score	−0·43	−1·11, 0·24	−0·37	−1·06, 0·26	−0·48	−1·03, 0·55	0·737	0·749
BMI-for-age *Z*-score	0·02	−0·57, 0·77	−0·06	−0·78, 0·67	0·07	−0·95, 0·97	0·879	0·025*

P25, 25th percentile; P75, 75th percentile.
*$P < 0·05$ following ANOVA analysis.

Table 2 Daily intakes of energy and nutrients (analysis of 24 h recalls), prevalence of inadequate intakes and recommended intakes, according to age group, among children aged 6–18 years (*n* 232), Eastern Cape, South Africa

	Age 6–8 years (*n* 55, 23·5 %)				Age 9–13 years (*n* 82, 35·0 %)				Age 14–18 years (*n* 97, 41·5 %)				
	24 h recall		Prevalence of inadequate intake (%)	EAR[31–34]/ WHO guideline[35]	24 h recall		Prevalence of inadequate intake (%)	EAR[31–34]/ WHO guideline[35]	24 h recall		Prevalence of inadequate intake (%)	EAR[31–34]/ WHO guideline[35]	Significant differences between groups, two-sided *P* value
Nutrient	Median	P25, P75			Median	P25, P75			Median	P25, P75			
Energy (kJ)	6149	4476, 7614	80·4	7316 (b)/6896 (g)	7172	6083, 8599	90·4	9572 (b)/6898 (g)	7141	5700, 9370	83·7	13 238 (b)/9940 (g)	0·001*
Total fat (g)	42 25·8 E%	25, 58		30-35 E%	48 25·3 E%	31, 63		30–35 E%	50 26·5 E%	15, 37		30-35 E%	0·147
SFA (g)	13 8·0 E%	13, 19		<10 E%	15 7·9 E%	11, 21		<10 E%	15 7·9 E%	9, 21		<10 E%	0·847
MUFA (g)	15 9·2 E%	9, 20		Balance†	16 8·4 E%	11, 22		Balance†	16 8·5 E%	11, 22		Balance†	0·763
PUFA (g)	10 6·1 E%	6, 13		6–11 E%	12 6·3 E%	7, 18		6–11 E%	12 6·4 E%	8, 21		6–11 E%	0·823
TFA (g)	1·5 0·9 E%	0·6, 2·4		<1 E%	1·7 0·9 E%	1·7, 2·6		<1 E%	1·4 0·7 E%	0·6, 2·6		<1 E%	0·376
Linoleic acid (g) (*n*-6; 18 : 2)	8·4 5·2 E%	4·5, 12·2		2·5–9 E%	8·9 4·7 E%	5·2, 14·6		2·5–9 E%	10·2 5·4 E%	5·5, 18·5		2·5–9 E%	0·770
Linolenic acid (g) (*n*-3; 18 : 3)	0·3 0·2 E%	0·2, 0·4		0·5–2 E%	0·3 0·2 E%	0·2, 0·5		0·5–2 E%	0·2 0·1 E%	0·2, 0·4		0·5–2 E%	0·022*
Fe (mg)	5·0	4·0, 6·5	46·4	4·1	6·4	4·9, 8·0	50·6	5·9 (b)/5·7 (g)	6·5	4·9, 8·4	66·3	7·7 (b)/7·9 (g)	0·011*
Mg (mg)	160·2	133·0, 193·1	23·1	110	207·0	170·3, 245·7	55·4	200	205·6	167·8, 244·0	86·7	340 (b)/300 (g)	0·004*
Zn (mg)	5·0	3·8, 6·50	37·5	4·0	6·0	5·0, 7·4	74·7	7·0	6·4	4·7, 7·6	80·6	8·5 (b)/7·5 (g)	0·083
Folate (μg)	112·3	77·0, 176·3	71·4	160	145·5	104·9, 196·1	80·7	250	143·3	105·1, 212·7	81·6	330	0·012*
Vitamin C (mg)	20·0	11·3, 32·4	67·9	22	23·8	15·0, 34·0	83·1	39	18·1	13·1, 38·3	89·8	63 (b)/56 (g)	0·898

P25, 25th percentile; P75, 75th percentile; EAR, Estimated Average Requirement; TFA, *trans*-fatty acids; E%, percentage of energy; b, boy, g, girl.
*$P < 0·05$ following ANOVA for each age group, energy controlled for.
†Balance = total fat − (SFA + TFA + PUFA).

Table 3 Diet quality parameters of children aged 6–18 years (*n* 232), by category of high-sensitivity C-reactive protein (hs-CRP) level, Eastern Cape, South Africa

	hs-CRP category						Significant differences between groups, two-sided	Significant differences between genders, two-sided
	Low (<1·0 mg/l)		Medium (1·0–3·0 mg/l)		High (>3·0 mg/l)			
Parameter	Median	P25, P75	Median	P25, P75	Median	P25, P75	*P* value	*P* value
Dietary intake								
Total energy intake (kJ)	6948·5	5396·6, 8464·7	7161·8	5615·3, 8049·2	6618·2	5826·3, 9108·2	0·533	0·610
Total fat intake (g)	45·7	28·5, 65·9	47·7	32·7, 61·9	45·4	28·8, 66·1	0·785	0·382
PUFA (g)	12·6	6·8, 19·2	10·3	6·5, 18·2	12·0	6·7, 19·4	0·823	0·212
MUFA (g)	15·0	10·1, 21·7	16·4	11·2, 21·5	14·4	10·4, 23·2	0·763	0·714
SFA (g)	14·6	9·0, 20·1	15·0	11·0, 20·6	14·0	8·5, 20·2	0·847	0·567
TFA (g)	1·6	0·7, 2·5	1·7	0·7, 2·7	1·1	0·7, 2·3	0·376	0·912
Fe (mg)	5·9	4·4, 7·9	6·1	4·6, 7·7	6·3	5·1, 9·0	0·046*	0·323
Zn (mg)	5·5	4·3, 7·2	5·9	4·8, 7·3	6·3	4·8, 7·9	0·018*	0·405
Mg (mg)	188·2	139·1, 239·8	193·3	166·7, 238·4	194·2	155·9, 244·4	0·299	0·971
Vitamin C (mg)	20·1	10·9, 29·9	19·2	13·5, 33·4	27·6	15·1, 52·1	0·002*	0·133
Folate (μg)	140·1	94·6, 173·3	129·8	87·6, 199·9	169·6	106·1, 239·1	0·019*	0·378
Linoleic acid (18 : 2) (g)	11·2	5·2, 16·4	8·1	3·4, 16·6	7·6	3·3, 20·0	0·770	0·235
Linolenic acid (18 : 3) (g)	0·2	0·17, 0·4	0·3	0·3, 0·4	0·3	0·2, 0·5	0·022*	0·599
E% from fat	23·7	20·5, 30·3	25·6	20·3, 30·0	25·7	18·1, 29·2	0·734	0·532
E% from protein	12·6	10·9, 14·8	12·6	10·9, 14·8	12·3	11·6, 14·8	0·157	0·525
E% from carbohydrates	57·7	54·3, 62·7	57·7	54·3, 62·7	58·4	52·5, 64·5	0·604	0·451
E% from total dietary fibre	2·9	2·4, 3·7	2·9	2·4, 3·7	3·3	2·6, 3·7	0·255	0·505
Dietary diversity								
FVS	20·0	17·0, 27·0	21·0	17·0, 28·0	22·0	18·5, 29·5	0·593	0·053
DDS	8·0	7·0, 9·0	8·0	7·0, 9·0	8·0	7·0, 9·0	0·607	0·218
Flesh food group (FGDS)	3·0	3·0, 4·0	3·0	2·0, 4·0	4·0	3·0, 4·0	0·468	0·080
Egg group (FGDS)	1·0	1·0, 1·0	1·0	1·0, 1·0	1·0	1·0, 1·0	1·000	1·000
Dairy group (FGDS)	2·0	1·0, 2·0	1·0	1·0, 2·0	2·0	1·0, 3·0	0·204	0·158
Cereal group (FGDS)	7·0	6·0, 8·0	7·0	5·0, 8·0	7·0	6·0, 8·0	0·631	0·144
Legume group (FGDS)	1·0	1·0, 2·0	1·0	1·0, 2·0	1·0	1·0, 2·0	0·509	0·224
Vitamin A-rich food group (FGDS)	2·0	1·0, 3·0	2·0	1·0, 3·0	2·0	1·0, 3·0	0·751	0·564
Fruit group (FGDS)	2·0	1·0, 3·0	2·0	1·0, 3·0	2·0	1·0, 4·0	0·544	0·190
Vegetable group (FGDS)	2·0	1·0, 4·0	3·0	2·0, 4·0	3·0	2·0, 5·0	0·227	0·228
Fat group (FGDS)	2·0	1·0, 2·0	2·0	1·0, 2·0	2·0	1·3, 3·0	0·295	0·382

P25, 25th percentile; P75, 75th percentile; TFA, *trans*-fatty acids; E%, percentage of energy; DDS, dietary diversity score; FVS, Food Variety Score; FGDS, Food Group Diversity Score.
*$P < 0·05$ following ANOVA analysis for low, medium and high inflammatory groups, energy controlled for.

observed in those children with medium and high levels of hs-CRP, thus medium and high levels of inflammation when compared with those with low levels of hs-CRP (Table 3).

Significant correlations between hs-CRP and dietary intake variables are shown in Table 4. No significant differences were observed in the median intakes of the inflammatory food components of the groups (data not shown).

We also explored the dietary diversity and food group diversity within the hs-CRP categories; however, no significant associations were observed. Generally poor dietary intake may have constrained the statistical power for examining the impact of diet quality on hs-CRP levels. Therefore, the high hs-CRP levels were most likely, in this instance, related to other confounding factors such as socio-economic status. This was explored further, revealing significant inverse relationships between hs-CRP and house size and presence of a toilet. Household income, caregiver education and employment status showed no significant correlations with hs-CRP, but the employment status of the child caregiver/legal guardian showed significant positive relationships with various nutrients and food groups (Table 4).

Discussion

Both over- and undernutrition were prevalent in the children in the present study, once again confirming that South Africa is a country in nutrition transition[40]. Although no obesity was found, overweight was prevalent in 4·2% of all children. This is much lower than found in the South African National Health and Nutrition Examination Survey data, which showed a much higher prevalence of both overweight (11·5% for boys, 16·5% for girls aged 2–14 years) and obesity (4·7% for boys, 7·1% for girls aged 2–14 years)[7]. However, risk of overweight

Table 4 Significant* correlations between measured variables among children aged 6–18 years (*n* 232), Eastern Cape, South Africa

Parameter	Correlation (*r*)	Significance (*P*)
hs-CRP and:		
Dietary total fat intake	−0·129	0·050
Dietary vitamin C intake	0·230	0·000
Dietary Fe intake	0·138	0·036
Dietary Zn intake	0·143	0·029
Dietary folate intake	0·147	0·025
Dietary linolenic acid (18 : 3) intake	0·148	0·024
Number of rooms	−0·214	0·002
Presence of a toilet in the home	−0·204	0·003
Employment status of the child caregiver/legal guardian and:		
Caregiver age	0·143	0·039
Legume group (FGDS)	0·176	0·011
Vitamin A food group (FGDS)	0·174	0·011
Vegetable group (FGDS)	0·137	0·047
FVS	0·165	0·017
Total carbohydrate intake	0·167	0·015
Total dietary fibre intake	0·255	0·000
Total folate intake	0·230	0·001
Total vitamin C intake	0·163	0·018

hs-CRP, high-sensitivity C-reactive protein; FGDS, Food Group Diversity Score; FVS, Food Variety Score.
Values are the correlation (*r*) following Pearson and Spearman correlations for nominal and categorical variables, respectively.
*$P<0·05$.

was high at 14·0 % in all children of the present study, with the boys being more at risk (18·1 %) than the girls (10·0 %). Stunting was observed in both genders (3·8 %), but was higher in girls (5·6 %) than boys (2·3 %). This finding is consistent with the data from the dietary assessment, confirming chronic insufficient food and nutrient intake and/or frequent infection[39]. In addition, the median hs-CRP level of 2·3 mg/l, which is classified as a medium hs-CRP level, indicated risk of chronic low-grade inflammatory status[1,6,9]. When considering the hs-CRP categories, there were no significant differences between the groups. It is interesting to note that only 31·5 % had no inflammation, while 49·5 and 19·0 % had medium and high hs-CRP levels, respectively, despite the median hs-CRP level being lower than the cut-off for acute inflammation[3]. These levels were unexpectedly high in this group of apparently healthy children. According to Nazmi and Victora, hs-CRP is a reliable marker for low-grade inflammation[3]. The pro-inflammatory nature of CRP under certain conditions may be associated with future NCD risk[3]. The hs-CRP levels of the majority of the children in the present study, irrespective of nutritional status, indicate high risk of low-grade inflammation.

Research has shown that a healthy diet during childhood can protect against malnutrition, inflammation and future disease risk[9]. Markers of an unhealthy diet include inflammatory components linked to hs-CRP levels, such as high intakes of certain nutrients (e.g. total fat and SFA) and certain food items (e.g. fried foods, sweets, confectionery, processed meats and soft drinks). On the other hand, anti-inflammatory components include nutrients such as dietary Zn, Fe, Mg, vitamin C, β-carotene, folate, linolenic acid and linoleic acid, as well as foods such as whole grains, fruit, vegetables and dairy foods[4,9]. In the present study, the intakes of Fe, Mg and Zn increased with age; however, the percentage of children with inadequate intakes of Mg, Zn, folate and vitamin C increased progressively with age, thus indicating older children being at risk of having poor micronutrient intakes.

Low total fat intake of less than 30 % of total energy intake was observed in the current study. SFA, PUFA, MUFA, *trans*-fatty acid and linoleic acid intakes recorded percentages in line with the guidelines for the prevention of chronic disease, whereas linolenic acid intakes were much lower than the recommended goal of 0·5–2 %[35]. Fe, vitamin C, Zn and linolenic acid intakes were all categorised by Lazarhou and Philippou as health-protecting[9]. Interestingly, intakes of all these nutrients appeared to increase significantly from the low hs-CRP to the high hs-CRP category, indicating that higher intakes were observed with inflammation. These results contradict those presented in the review of six previous studies[9] and were further confirmed by the significant positive correlations between hs-CRP and dietary intake variables, except for total fat intake that showed an unexpected inverse relationship with hs-CRP. This contrasts with the positive relationship reported by Aerberli *et al.*[41].

We also explored the dietary diversity and food group diversity within the hs-CRP categories; however, no significant associations were observed. This is most likely due to the infrequent consumption of different food items within the food groups (low food variety) and the resultant low nutrient intakes. The majority of the children had a high FGDS median (dietary diversity score), but a low FVS. This indicates that although most food groups were consumed, only a limited number of foods from each group were consumed in the 7 d period. The children's diets generally consisted of only seven different cereals, six to seven different vegetables and fruits, three different flesh foods, two dairy foods, and one legume and one egg dish consumed over a period of one week. Consuming one or two foods from each of the nine groups does not, therefore, constitute a varied intake. The food intakes of this group of children were thus not in line with the South African Food-Based Dietary Guideline of 'eat a variety of foods'. Vegetables, fruit and whole grains are rich sources of antioxidants (Zn, vitamin C, vitamin E and β-carotene), which assist in managing oxidative stress in the body. These nutrients further assist in reducing subclinical inflammation[4,6]. In the present study, low intakes of these food groups and antioxidant nutrients were observed. Low intakes of antioxidant vitamins have, furthermore, been associated with obesity in children[6], which could have explained the high prevalence of risk of overweight in these children. No significant relationships between hs-CRP and any of the food groups could be established in the current study, but significant inverse relationships were established for house size in terms of

number of rooms and hygienic ablution facilities with hs-CRP levels. Thus, those children living in bigger houses and those with the presence of a toilet in the house showed lower risk of inflammation. In this instance, socio-economic factors thus were significantly associated with the inflammatory status of these children. A study undertaken in nearby Mthatha showed that 60 % of primary-school learners tested positive for intestinal parasitic infections, often associated with poverty and poor environmental hygiene[42]. Parasitic infections may also have contributed to the high levels of inflammation observed in the study children; however, this was not determined in the study. Furthermore, resource-poor households are often deprived not only of access to food, but also of a variety of high-quality nutritious foods[43]. Poor people often purchase cheaper, energy-dense foods that are most satiating, resulting in nutrient-poor diets with low variety within food groups[7]. In the current study, a significant positive relationship was observed between the employment status of the child caregiver and dietary fibre, folate and vitamin C, as well as the legume, vitamin A-rich and vegetable food group intakes. Although it seems as if sociodemographic factors were more associated with inflammation in these children, the importance of diet quality, specifically dietary diversity, should not be underestimated as a varied diet is positively associated with many health outcomes such as child anthropometric status, improved Fe status and birth weight. Furthermore, although sociodemographic factors are important determinants associated with household food security, access to and consumption of a variety of foods are needed to achieve nutrition security[44].

The present study has several limitations, including the availability of only two 24 h dietary recalls that provided a less accurate measure of dietary intake. This may have resulted in reducing the power to detect accurate relationships, specifically for foods not eaten frequently and for seasonal variations. However, the data were collected by trained and experienced fieldworkers, and food models and household utensils were used for the estimation of portion sizes. Second, although the sample size is representative of this community, the results should not be generalised to other socio-economic groups or communities within the Eastern Cape.

Conclusions

To our knowledge, the present study is the first to explore the relationship between dietary quality and hs-CRP in a resource-poor setting in South Africa. The conclusions can be summarised as follows:

1. The hs-CRP levels of the majority of the study children indicate a high risk of low-grade inflammation.
2. Although no link could be established between over-nutrition and hs-CRP levels, a significantly positive association was found between hs-CRP and some of the anti-inflammatory nutrients, contradicting results from other studies[9,41]. Our study thus found no protective effect of the anti-inflammatory nutrients on inflammation.
3. Larger house size and the presence of ablution facilities showed a positive association with inflammation, thus there was less inflammation with the presence of these two sociodemographic markers. No other associations were observed.

Evidence from the limited research in this area is contradictory. Owing to the complex nature of diet quality assessments, it is difficult to pinpoint the effects of different micronutrients and/or foods and groups. Future research is recommended as follows:

1. Dietary quality, particularly inflammatory and anti-inflammatory nutrients and food components, and their association with inflammatory markers such as hs-CRP should be investigated further to gain a better understanding of this relationship in both low and high socio-economic groups.
2. Although the precise significance of the association of hs-CRP with obesity and adiposity has not been determined in children[4], more research should be conducted to establish the link with NCD to plan suitable interventions for the prevention of these diseases in the long term.

Acknowledgements

Acknowledgements: The authors wish to thank the community leaders and participants in this study, as well as the fieldworkers for their valuable assistance. *Financial support:* This project was funded by the Department of Trade and Industry (Dti) and the Council for Scientific and Industrial Research (CSIR) in South Africa. The Dti funded the project and the CSIR was the implementation agency. W.O.-T. and her research team was sub-contracted for data collection, analysis, interpretation and dissemination. The Dti and CSIR used the data to plan and implement an intervention study. *Conflict of interest:* None. *Authorship:* W.O.-T. was responsible for the conceptualisation of the study as well as ethics approval, data collection and analyses. Both authors were involved in the preparation of the manuscript. *Ethics of human subject participation:* The Research and Innovation Ethics Committee of the Vaal University of Technology (VUT) approved the study protocol (approval number 20130520-3). Research was conducted according to the Declaration of Helsinki and the South African Medical Research Council's guidelines for research on human beings. Written informed consent was obtained from the children's caregivers/legal guardians as well as from respondents aged 7 years or older after an explanation of the objectives and study procedures.

References

1. Misra A (2004) C-reactive protein in young individuals: problems and implications for Asian Indians. *Nutrition* **20**, 478–481.
2. Pearson TA, Mensah GA, Alexander WA *et al.* (2003) Markers of inflammation and cardiovascular disease: application to clinical and public health practice: a statement for healthcare professionals from the Centers for Disease Control and Prevention and the American Heart Association. *Circulation* **107**, 499–511.
3. Nazmi A & Victora CG (2007) Socioeconomic and racial/ethnic differentials of C-reactive protein levels: a systematic review of population-based studies. *BMC Public Health* **7**, 212.
4. Kuczmarski MF, Mason MA, Allegro D *et al.* (2013) Diet quality is inversely associated with C-reactive protein levels in urban, low-income African-American and white adults. *J Acad Nutr Diet* **113**, 1620–1630.
5. Rietszell E & De Buyzere M (2012) Biomarkers in medicine. *Future Med* **6**, 19–34.
6. Qureshi MM, Singer MR & Moore LL (2009) A cross-sectional study of food groups intake and C-reactive protein among children. *Nutr Metab (Lond)* **6**, 40.
7. Shisana O, Labadarios R, Rehle T *et al.* (2013) *South African National Health and Nutrition Examination Survey (SANHANES-1)*. Cape Town: HSRC Press.
8. Mayosi BM, Flisher AJ, Lalloo UG *et al.* (2009) The burden of non-communicable diseases in South Africa. *Lancet* **374**, 934–947.
9. Lazarou C & Philippou E (2013) C-Reactive protein and diet quality in children. In *Diet Quality: An Evidence-Based Approach*, pp. 75–100 [VR Preedy, LA Hunter and VB Patel, editors]. London: Humana Press.
10. King DE, Egan BM & Geesey ME (2003) Relation of dietary fat and fibre to elevation of C-reactive protein. *Am J Cardiol* **92**, 1335–1339.
11. Ajani UA, Ford ES & Mokdad AH (2004) Dietary fiber and C-reactive protein: findings from national and health examination survey data. *J Nutr* **134**, 1184–1185.
12. Lopez-Garcia E, Schulze MB, Fung TT *et al.* (2004) Major dietary patterns are related to plasma concentrations of markers of inflammation and endothelial dysfunction. *Am J Clin Nutr* **80**, 1029–1035.
13. Kontogianni MD, Zampelas A & Tsigos C (2006) Nutrition and inflammatory load. *Ann N Y Acad Sci* **1083**, 214–238.
14. Fleming JA & Kris-Etherton PM (2014) The evidence for α-linolenic acid and cardiovascular disease benefits: comparisons with eicosapentaenoic acid and docosahexaenoic acid. *Adv Nutr* **5**, issue 6, 863S–876S.
15. Fraker PJ, King LE, Laakko T *et al.* (2000) The dynamic link between the integrity of the immune system and zinc status. *J Nutr* **130**, 5S Suppl., 1399S–1406S.
16. Oppenheimer SJ (2001) Iron and its relation to immunity and infectious disease. *J Nutr* **131**, 2S-2, 616S–633S.
17. Dibaba DT, Xun P & He K (2014) Dietary magnesium levels is inversely associated with serum C-reactive protein levels: meta-analysis and systematic review. *Eur J Clin Nutr* **68**, 510–516.
18. Guerrero-Romero F & Rodriquez-Morán M (2002) Relationship between serum magnesium levels and C-reactive protein concentration, in non-diabetic, non-hypertensive obese subjects. *Int J Obes Relat Metab Disord* **26**, 469–474.
19. Garcia-Diaz DF, Lopez-Legarrea P, Quintero P *et al.* (2014) Vitamin C in the treatment and/or prevention of obesity. *J Nutr Sci Vitaminol (Tokyo)* **60**, 367–379.
20. Shivappa N, Steck SE, Hurley TG *et al.* (2014) Designing and developing a literature-derived, population-based dietary inflammatory index. *Public Health Nutr* **17**, 1689–1696.
21. Santos S, Oliveira A & Lopes C (2013) Systematic review of saturated fatty acids on inflammation and circulating levels of adipokines. *Nutr Res* **33**, 687–695.
22. Schulze MB, Hoffmann K, Manson JE *et al.* (2005) Dietary pattern, inflammation, and incidence of type 2 diabetes in women. *Am J Clin Nutr* **82**, 675–684.
23. Gibson R (2006) *Dietary Methodology. Notes of a Three-Day Nutrition Society South Africa Workshop from 12–14 September 2006 in Potchefstroom, South Africa*. New Zealand: University of Otago.
24. Oldewage-Theron WH, Dicks EG, Napier CE *et al.* (2005) Situation analysis of an informal settlement in the Vaal Triangle. *Dev South Afr* **22**, 13–26.
25. Gibson RS (2005) *Principles of Nutritional Assessment*, 2nd ed. New York: Oxford University Press.
26. Matla MTH (2008) The contribution of food access strategies to dietary diversity of farmworker households on Oranje farm in the Fouriesburg district (RSA). MSc Dissertation, University of Pretoria.
27. Food and Agriculture Organization of the United Nations (2006) Baseline Survey Report Protecting and Improving Household Food Security and Nutrition in HIV/AIDS Affected Areas in Manica and Sofala Province, Maputo, Mozambique. http://www.fao.org/fileadmin/user_upload/eufao-fsi4dm/doc-training/baseline_june07.pdf (accessed July 2016).
28. Centers for Disease Control and Prevention (2007) *National Health and Nutrition Examination Survey (NHANES) Anthropometric Procedures Manual*. Atlanta, GA: CDC.
29. World Health Organization (2007) The WHO Child Growth Standards. http://www.who.int/childgrowth/standards/en/ (accessed April 2014).
30. Langenhoven M, Kruger M, Gouws E *et al.* (1991) *MRC Food Composition Tables*, 3rd ed. Parow: Medical Research Council.
31. Institute of Medicine, Food and Nutrition Board (2002) *Dietary Reference Intakes for Energy, Carbohydrate, Fiber, Fat, Fatty Acids, Cholesterol, and Protein and Amino Acids*. Washington, DC: National Academy Press.
32. Institute of Medicine, Food and Nutrition Board (2001) *Dietary Reference Intakes for Vitamin A, Vitamin K, Arsenic, Boron, Chromium, Copper, Iodine, Iron, Manganese, Molybdenum, Nickel, Silicon, Vanadium and Zinc*. Washington, DC: National Academy Press.
33. Institute of Medicine, Food and Nutrition Board (2000) *Dietary Reference Intakes for Vitamin C, Vitamin E, Selenium and Carotenoids*. Washington, DC: National Academy Press.
34. Institute of Medicine, Food and Nutrition Board (1998) *Dietary Reference Intakes for Thiamine, Riboflavin, Niacin, Vitamin B_6, Folate, Vitamin B_{12}, Pantothenic Acid, Biotin and Choline*. Washington, DC: National Academy Press.
35. Food and Agricultural Organization of the United Nations & World Health Organization (2010) *Fats and Fatty Acids in Human Nutrition. Report of an Expert Consultation*. Rome: FAO.
36. Ruel MT (1998) Operationalizing dietary diversity: a review of measurement issues and research priorities. *J Nutr* **133**, 11 Suppl. 2, 3911S–3926S.
37. Hatloy A, Torheim LE & Oshaug A (1998) Food variety – a good indicator of nutritional adequacy of the diet? A case study from an urban area in Mali, West Africa. *Eur J Clin Nutr* **52**, 891–898.
38. United Nations Development Programme (2012) Eradicate extreme poverty and hunger. http://www.undp.org/content/undp/en/home/mdgoverview/mdg_goals/mdg1/ (accessed October 2014).

39. UNICEF (2007) *Progress for Respondents: A World Fit for Children. Statistical Review* no. 6. New York: UNICEF.
40. Vorster HH & Bourne L (2008) The nutrition transition in South Africa. In *Community Nutrition Textbook for South Africa: A Rights-Based Approach*, pp. 233–250 [NP Steyn and NE Temple, editors]. Cape Town: Chronic Diseases of Lifestyle Unit, MRC.
41. Aerberli I, Molinari L, Spinas G *et al*. (2006) Dietary intakes of fat and antioxidant vitamins are predictors of subclinical inflammation in overweight Swiss children. *Am J Clin Nutr* **84**, 745–755.
42. Nxasana N, Baba K, Bhat VG *et al*. (2013) Prevalence of intestinal parasites in primary school children of Mthatha, Eastern Cape Province, South Africa. *Ann Med Health Sci Res* **3**, 511–516.
43. Argüelles MdCZ (2010) Poverty and vulnerability in Cuba today. *Socialism and Democracy* **24**, 109–126.
44. Labadarios D, Steyn NP & Nel J (2011) How diverse is the diet of adult South Africans? *Nutr J* **10**, 33.