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Associations between Arterial Compliance and Anthropometry of Children from Four Ethnic Groups in South Africa: The THUSA BANA Study

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Aim: To investigate whether associations and differences exist regarding the arterial compliance, dietary intake and anthropometric parameters of children of four different ethnic groups in South Africa. **Study design:** In this study, 1244 children from four ethnic groups, aged 10–15 years, were randomly selected from five regions of the North West Province. Blood pressure was measured with a Finapres apparatus and analysed to obtain systemic arterial compliance. Measurements were done to obtain body mass index (BMI), waist-to-hip ratio and percentage body fat. Dietary intake was determined with a 24-h dietary recall questionnaire. **Results:** The black and mixed-origin subjects indicated the lowest values ($p \leq 0.05$) for BMI, percentage body fat, and dietary intake, whereas the white and Indian subjects showed significantly higher values than the other ethnic groups. The white and Indian children had significantly higher arterial compliance than the black and mixed-origin children at all ages from 10 to 15 years. Compliance showed significant correlations with all anthropometric parameters. **Conclusion:** Since black and mixed-origin children have the highest prevalence of undernutrition and stunted growth, it is suggested that parental undernutrition and inadequate nutrition in early life, associated with lower arterial compliance, may lead to the onset of adult hypertension. **Key words:** arterial compliance, ethnicity, hypertension, race, undernutrition.

INTRODUCTION

Ethnic differences in the prevalence of adult hypertension are well known [1]. The African-American adults are known to have higher blood pressure than Hispanic or non-Hispanic white adults [1], whereas Mexican American adults do not have an increased prevalence of hypertension [2], although they have a higher prevalence of cardiovascular risk factors than non-Hispanic whites [3].

Conflicting results have been reported in the paediatric literature regarding ethnic differences in blood pressure levels in children and adolescents [4–6]. Although clinical hypertension occurs less frequently in children than in adults [7–9], ample evidence supports the concept that the roots of essential hypertension extend back to childhood. Of particular importance is the documentation that elevated blood pressure in childhood often correlates with hypertension in early adulthood, thereby supporting the need to track blood pressure in children [10]. Studies of blood pressure in African-American, Hispanic and non-Hispanic children showed no consistent, statistically significant differences in blood pressure levels among

children and adolescents, regardless of adjustment for weight or use of auscultatory or oscillometric method [3, 5], but there are also studies that indicated opposite results [4, 11].

In the South African population of just over 43 million in 2000 – comprising of 77.6% Africans (black), 2.5% Asians (Indian), 8.7% mixed origin and 10.4% whites (European) [12] – clear differences in the prevalence of hypertension have been observed. It has been indicated that food poverty rates were highest among households with the worst socio-economic conditions, headed by Africans, followed by people of mixed origin, Indians and whites [13]. These different ethnic groups indicated prevalences of hypertension that varied from 14.2% in Indians, 17.2% in whites [14], 22.2% in blacks [15] and 30.2% in the mixed-origin group [16]. However, very little is known regarding blood pressure in children of the various ethnic groups of South Africa.

Although blood pressure is the most frequently measured parameter of the peripheral vasculature, other properties such as arterial compliance, may be a more subtle index of vascular dysfunction associated with diseases such as hypertension [17]. Vascular compliance

is defined as the change in volume of the artery per unit of pressure ($\Delta V/\Delta P$) [18]. Arterial compliance can also be estimated from the simpler approach of stroke volume divided by pulse pressure [19] and it reflects both the arterial capacity and viscoelastic properties of the arterial wall. Arterial compliance is influenced by various conditions. It has been shown that with aging, compliance of large arteries decreases [20]. It has also been shown that severe obesity in children is associated with arterial wall stiffness (low arterial compliance) [21]. Other anthropometric factors, such as body size (stature), are also strongly associated with arterial compliance [22].

According to the World Health Organization [23], there is very little direct evidence about the determinants of common cardiovascular diseases in populations of sub-Saharan Africa. The aim of this study was therefore to investigate whether associations and differences exist regarding the cardiovascular and anthropometric parameters and dietary intake of children of four different ethnic groups. This study forms part of the larger THUSA BANA study (Transition and Health during Urbanization in South Africa in Children; Bana: the Setswana word for Children), which was designed to assess the health status of children in the North West Province of South Africa.

METHODS

Study design

This was an epidemiological, cross-sectional study. Forty-four schools were randomly selected from a list of schools in the five regions of the North West Province of South Africa. These schools were visited during the weeks preceding the collection of data, in order to obtain permission from the relevant school principals as well as from the parents of the children. Children within the schools were also randomly selected from class lists. Data collection took place during normal school hours.

Subjects

A total of 1244 apparently healthy children between 10 and 15 years of age were recruited from the 44 schools over a period of 2 years (2000–2001). The subjects consisted of black, white, Indian and mixed-origin children of both sexes. Equal percentages of younger and older subjects were included in each of the four race groups. Because of the magnitude of the project, all subjects were not necessarily subjected to all measurements.

The Ethics Committee of the Potchefstroom University for Christian Higher Education has approved the study and the study protocol conforms to the ethical guidelines of the 1975 Declaration of Helsinki. All parents of the THUSA BANA subjects gave informed consent.

Data collection and measurements

The subjects were all introduced to the experimental setup, after which each one was separately subjected to the following procedures:

Cardiovascular parameters

The subjects were connected to a Finapres (finger-arterial pressure) apparatus [24, 25] and blood pressure was recorded continuously. After a period of rest of at least 10 min, resting blood pressure values were obtained. Blood pressure was regarded as resting when the systolic blood pressure did not change with more than 10 mmHg during the last minute of this period, otherwise the resting period was extended. The resting blood pressure was then recorded continuously for 1 min. The data was stored on magnetic tape by means of a Kyowa RTP-50A four-channel data recorder and digitized for further analysis by means of the Fast Modelflow software program [26]. The Modelflow method digitally computes an aortic-flow waveform from a peripheral arterial pressure signal [26]. It uses a non-linear three-element model (Windkessel) of the aortic input impedance consisting of aortic characteristic impedance, arterial compliance and peripheral vascular resistance [26]. In this way the systolic (SBP), and diastolic blood pressure (DBP), and arterial compliance (C) were obtained.

The vascular unloading technique of Penáz together with the Physiological criteria of Wesseling provided reliable, non-invasive and continuous estimates of blood pressure [25, 27]. This technique is thus an alternative to the invasive intra-arterial measurements, without the risks and ethical questions inherent to invasive measurements. Since the pressure waveform is available continuously, computations provide further information on the dynamics of the cardiovascular system on a beat-to-beat basis, similar to intra-arterial measurements [26, 28–30].

Anthropometric measurements

Anthropometric measurements were done by qualified anthropometrists under guidance of a level III anthropometrist, according to standard methods as described by Norton & Olds [31]. Maximum height was measured to the nearest 0.1 cm by means of a stadiometer with the head in the Frankfort plane. Body mass was measured to the nearest 0.1 kg by means of a calibrated electronic scale (Precision Health scale) with the subject wearing the minimum clothing. The waist and hip girths of the subjects were measured with a flexible Lufkin steel anthropometric tape to the nearest 0.1 cm. During these measurements, the subject had to stand erect with the feet together and without volitionally contracting the gluteal muscles.

The following equations were used to determine body

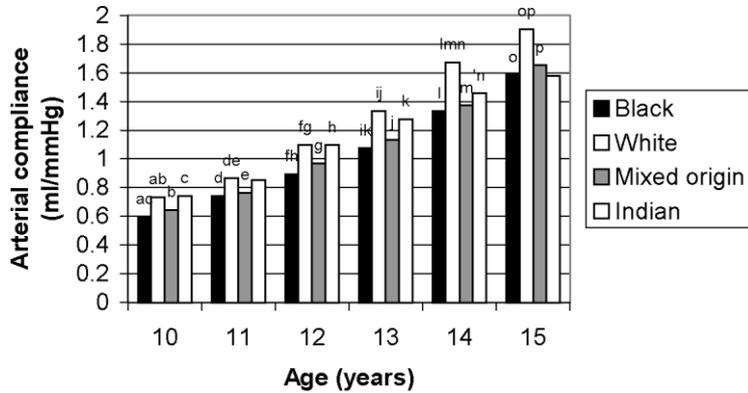


Fig. 1. Stepwise increase in arterial compliance with age, corrected for height. Columns with the same superscript letter differ significantly ($p \leq 0.05$).

mass index and waist-to-hip ratio [31]: BMI = body mass (kg)/stature² (m); WHR = waist girth (cm)/hip girth (cm).

Skin-fold measurements were taken using a Harpenden Skin-fold caliper with a jaw pressure of 10 g/mm² and were taken to the nearest 0.2 mm by using the standard methods as described by Norton & Olds [31]. Percentage body fat was calculated according to the equation of Boileau *et al.* [32].

Dietary intake

Dietary intake data were collected by fieldworkers trained by registered dietitians. A 24-h dietary recall was collected face-to-face and the data collection interview method and nutrient coding were the same for all recalls. Food models and photo books for portion-size estimates were used for the recalls. This type of dietary assessment is widely used in international epidemiological studies [33–35]. Macronutrients (protein, fat, and carbohydrate) and fibre were calculated, and micronutrients (such as potassium, sodium and iron) and vitamins (such as folic acid) were calculated in the appropriate units, using a

computer program based on the South African food composition tables [36].

Statistical analysis

All processed data was transferred to Microsoft Excel and further statistically analysed by means of the software computer package STATISTICA [37]. Due to skewed distributions all dietary variables were logarithmically transformed. Since the blood pressure and anthropometric parameters had a normal distribution, log transformations were not necessary. One-way analysis of variance (ANOVA) was used to determine whether statistical significant differences ($p \leq 0.05$) existed between the different ethnic groups as far as cardiovascular and anthropometric parameters are concerned. It was followed by multiple comparisons of the group means using the Tukey honest significant difference (HSD) test for unequal group sizes [37]. The one-way analysis of covariance (ANCOVA) was used to determine significant differences ($p \leq 0.05$) between the arterial compliance of the different age groups, correcting for height (Fig. 1).

Table I. Cardiovascular and anthropometric characteristics of the subjects

	<i>n</i>	SBP (mmHg)	DBP (mmHg)	C (ml/mmHg)	BMI (kg/m ²)	WHR	% BF	Body mass (kg)	Height (m)
Males									
Black	356	98.4 ± 14.5	64.1 ± 10.5	1.07 ± 0.39 ^a	16.6 ± 2.7 ^a	0.84 ± 0.07	13.7 ± 5.6 ^a	35.4 ± 10.1 ^a	144.9 ± 12.0 ^a
White	102	103.1 ± 14.5	65.4 ± 8.6	1.34 ± 0.50 ^{ab}	19.0 ± 3.8 ^{abc}	0.82 ± 0.08	17.3 ± 7.9 ^{ab}	47.5 ± 13.6 ^{abc}	157.0 ± 1.4 ^{ab}
Mixed origin	98	98.6 ± 12.5	63.5 ± 9.2	0.99 ± 0.33 ^b	16.3 ± 2.7 ^b	0.83 ± 0.04	14.0 ± 5.3 ^b	34.2 ± 8.3 ^b	144.1 ± 1.2 ^{bc}
Indian	43	95.6 ± 14.4	61.7 ± 9.4	1.15 ± 0.33	17.0 ± 3.3 ^c	0.82 ± 0.04	15.8 ± 5.8	39.5 ± 11.0 ^c	151.4 ± 10.9 ^c
Females									
Black	414	103.8 ± 15.4	66.6 ± 11.1	1.00 ± 0.37 ^a	18.1 ± 3.9	0.78 ± 0.07	22.1 ± 7.0	39.4 ± 11.7 ^a	146.3 ± 11.4 ^a
White	91	105.9 ± 13.8	64.8 ± 8.2	1.19 ± 0.41 ^{ab}	19.1 ± 2.9 ^a	0.77 ± 0.08	24.2 ± 5.9 ^a	46.5 ± 11.5 ^{ab}	154.9 ± 11.2 ^{ab}
Mixed origin	99	103.6 ± 14.4	65.5 ± 9.1	0.96 ± 0.37 ^b	17.2 ± 3.1 ^a	0.77 ± 0.05	21.3 ± 6.7 ^a	38.0 ± 10.7 ^b	147.4 ± 10.7 ^b
Indian	41	98.3 ± 14.4	63.4 ± 9.1	1.11 ± 0.35	18.0 ± 3.6	0.76 ± 0.08	24.5 ± 7.0	41.5 ± 10.2	151.5 ± 9.8

Means with the same superscript letter differ significantly ($p \leq 0.05$) and all significant differences have effect sizes ≥ 0.05 . Values are mean ± standard deviation. *n*, number of subjects; SBP, systolic blood pressure; DBP, diastolic blood pressure; BMI, body mass index; WHR, waist-to-hip ratio; %BF, percentage body fat.

Table II. Mean dietary intake of the lower (Group A) and higher socio-economic (Group B) groups

Dietary variables	Group A	Group B
	(Black and mixed origin)	(Indian and white)
Protein (g/day)	61.0 ± 0.8	64.1 ± 1.6
Animal protein (g/day)	29.5 ± 0.6	28.3 ± 1.1
Plant protein (g/day)	31.3 ± 0.5 ^b	35.7 ± 1.1 ^b
Saturated fat (g/day)	17.7 ± 0.4	16.9 ± 0.7
Fibre (g/day)	15.2 ± 0.3 ^b	17.6 ± 0.6 ^b
Iron (mg/day)	8.4 ± 0.2	8.7 ± 0.3
Magnesium (mg/day)	229.4 ± 3.6 ^a	246.9 ± 6.9 ^a
Potassium (mg/day)	1625.2 ± 28.1	1683.1 ± 52.2
Sodium (mg/day)	1585.4 ± 37.9	1644.4 ± 67.5
Folic acid (µg/day)	169.8 ± 4.5 ^a	186.5 ± 8.8 ^a

Values are mean ± standard error.

Significantly different: ^a $p \leq 0.05$; ^b $p \leq 0.001$, all significant differences have effect sizes ≥ 0.02 .

The independent *t*-test was used to determine statistically significant differences ($p \leq 0.05$) between the dietary intakes of the lower and higher socio-economic groups (Groups A and B). Effect sizes (*d*) were calculated with the equation:

$$d = \frac{x_1 - x_2}{SD}$$

(*x* = mean; SD = maximum standard deviation) and give an indication of the practical importance of the statistical significance [38]. Since the variables were normally distributed, the Pearson correlation coefficient was used to indicate statistical significant correlations ($p \leq 0.05$) between arterial compliance and the anthropometric variables.

RESULTS

The overall sample consisted of 599 male and 645 female subjects. The means and SDs of cardiovascular and anthropometric characteristics of these subjects are indicated in Table I, together with the results of the Tukey test. No significant differences were indicated for SBP and DBP between any of the groups. However,

arterial compliance of the white males and females indicated significantly higher values than the black and mixed-origin groups. From this table, it is also evident that the white male subjects had significantly higher BMI and body mass than the black, mixed-origin and Indian groups. They also had a significantly higher percentage body fat and height than the black and mixed-origin children. The Indian males had a significantly higher height than the mixed-origin males. The white female subjects also indicated a significantly higher BMI and percentage body fat than the mixed-origin females. They also indicated a significantly higher body mass and height than the black and mixed-origin females. The effect sizes (standardized differences) of the significant differences are indicators of practical importance, and indicate practical results of a medium to a large effect [38]. The black and mixed-origin subjects of both sexes indicated the lowest values for body mass, height, BMI and percentage body fat.

Table II provides the mean and standard errors of dietary intake data of the subjects within two groups. Subjects with lower socio-economic status and food poverty [13] were placed in Group A (black and mixed origin). These subjects were mostly subjected to living conditions in rural areas, on farms and in informal settlements. Subjects with higher socio-economic status were placed in Group B (Indian and white) in order to determine basic dietary differences between subjects from these backgrounds. These subjects lived mostly in established townships with full access to water and electricity and in upper class suburbs. It is evident from this data that subjects from a higher socio-economic background (white and Indian) had significantly higher ($p \leq 0.001$) intakes of plant protein and fibre, as well as ($p \leq 0.05$) magnesium and folic acid than those with lower socio-economic status (black and mixed origin). The effect sizes of these significant differences were small, meaning that these results are practical to use in a direction giving capacity [38].

With the aging process from 10 to 15 years, body size increases, which leads to an increase in the arterial tree, and an increased arterial compliance [39]. It is evident

Table III. Correlations between arterial compliance and anthropometric parameters

	Body mass index	Waist-to-hip ratio	Percentage body fat	Mass	Stature
Males	$r = 0.45$ $n = 540$ $p = 0.00001$	$r = -0.20$ $n = 540$ $p = 0.00001$	$r = 0.12$ $n = 539$ $p = 0.006$	$r = 0.82$ $n = 540$ $p = 0.00001$	$r = 0.91$ $n = 540$ $p = 0.00001$
Females	$r = 0.54$ $n = 561$ $p = 0.00001$	$r = -0.41$ $n = 560$ $p = 0.00001$	$r = 0.49$ $n = 560$ $p = 0.00001$	$r = 0.86$ $n = 561$ $p = 0.00001$	$r = 0.87$ $n = 562$ $p = 0.00001$

r, Pearson correlation coefficient; *n*, amount of subjects; *p*, statistical significance.

from Fig. 1, in which the arterial compliance of the four ethnic groups was compared (while correcting for height), that the white and Indian children of both sexes also had a significantly higher arterial compliance than did the black and mixed-origin children at all ages.

When the arterial compliance of the total subject group was correlated with the five anthropometric variables (Table III), statistical significant correlations ($p \leq 0.05$) between all anthropometric parameters and compliance were found. The compliance of the female subjects showed much stronger correlations with BMI, WHR and percentage body fat, than the males. The same phenomenon was also evident when the correlations were done within the separate ethnic groups.

DISCUSSION

Since arterial compliance consists of an arterial distensibility component but also an arterial volume component, it is reasoned that an increase in body size – as can be seen in the aging process – will be positively associated with increases in compliance [39]. However, it is not only body size influencing compliance at such a young age, since it is evident from Fig. 1 that significant differences in compliance exist between the four ethnic groups, although there has been corrected for body height.

The possibility of genetic predisposition of certain ethnic groups to present low arterial compliance cannot be ruled out, but since it is clear that compliance is strongly related to body size (Table III), the origin of lower arterial compliance might also be partially explained by nutritional deficiencies. In a review of the nutritional status of South Africans [40], one of the most important observations was that between 20% and 25% of preschoolers are stunted, and therefore suffer from chronic undernutrition. Black and mixed-origin children (lower socio-economic status) had the highest prevalences (25 and 17% respectively) of undernutrition, with rural black children being the most vulnerable group. Rural black children had low mean energy intakes and although total protein intakes seemed adequate, the quality of the protein may have been jeopardized. These results have been duplicated in this study, which showed that children of black and mixed origin had lower intakes of protein, especially plant protein, higher intakes of saturated fat and lower intakes of dietary fibre. The significantly lower intakes of fibre and folic acid in these groups are an indication that fruit and vegetable intakes are not adequate.

The parental dietary intake may also play a significant role in jeopardizing the cardiovascular health of the infant. Several lines of evidence support the thesis that it is poor or imbalanced delivery of nutrients that programmes raised blood pressure in humans. Numerous

animal experiments have shown that undernutrition *in utero* leads to fetal adaptations causing persisting changes in blood pressure [41].

It is therefore proposed that a vicious circle of events might be the cause of low arterial compliance in these children. The origin of this circle is parental undernutrition, in areas of low socio-economic support, which leads to children with low birth weight. This is followed by children predisposed to hypertension, and who are also subjected to undernutrition or malnutrition, thereby promoting the development of hypertension in later life.

It is suspected that household food insecurity, poverty, and other factors dictated by socio-economic realities, are more important determinants of nutrient intakes. It is clear that low energy density of weaning foods and of the diets of rural black primary school children, coupled to a low intake of fruits, vegetables, legumes and milk by many individuals are the main deficiencies in the South African diet [40].

The strong negative association of WHR of the female subjects (Table III) indicates that a high prevalence in abdominal obesity, especially in females, is associated with low arterial compliance. The black male and female subjects not only showed the lowest arterial compliance in all age groups (Fig. 1), but also showed the highest WHR, although not statistically significantly higher than the other ethnic groups. Vorster and co-workers [40] also stated that although a quarter of South Africa's children are stunted, very high prevalences of obesity are also evident, indicating that South Africans clearly have the double burden of both under- and malnutrition. The effects of stunted growth were clearly observed in the black children, as well as the children of mixed origin, who showed a significantly lower BMI, body mass, fat percentage and height than the white and Indian children. By calculating the body surface, the differences between these ethnic groups could have possibly been observed more clearly.

Parental undernutrition and inadequate nutrition in early life, associated with lower arterial compliance, could therefore lead to the onset of adult hypertension, since it has been demonstrated by Arnett *et al.* [42] that reductions in large or small arterial compliance occur early in adulthood before the appearance of hypertension. It is therefore suggested that vascular structural changes may already begin at an early age.

We conclude therefore that although there are not yet any significant differences in systolic and diastolic blood pressure between the four ethnic groups of children, there are clear significant differences in arterial compliance. This suggests that the differences in arterial compliance could be associated with the differences in the prevalence of adult hypertension between these four ethnic groups, but further study is needed. The black and mixed-origin

ethnic groups (lower socio-economic status) had the lowest arterial compliance in childhood in this study (Fig. 1) and other studies also indicated that these ethnic groups had the highest prevalence of hypertension in adulthood of 22.2% and 30.2%, respectively [15, 16]. The white and Indian groups of this study (higher socio-economic status) had the highest arterial compliance in childhood (Fig. 1), and these groups also indicated the lowest prevalence of adult hypertension of 17.2% and 14.2%, respectively [14] in South Africa. These findings suggest that low arterial compliance in childhood, associated with nutritional deficiencies and stunted growth (smaller body size), may have an association with hypertension in later life, but further study is needed to confirm this suggestion.

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