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Association of Neck Circumference with Pulse Pressure Among School-Aged Children in Ibadan, Nigeria: A Cross-Sectional Study

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Abstract

Background: Neck circumference is a simple marker of upper-body adiposity, but its relationship with pulse pressure in African children has received limited attention.

Objectives: To determine whether increasing neck circumference is associated with higher pulse pressure among school-aged children in Ibadan, Nigeria.

Methods: This school-based, cross-sectional study analysed 402 children aged 5-12 years selected by multistage stratified random sampling technique from public and private primary schools in Ibadan North Local Government Area. Height, weight, Body Mass Index (BMI), neck circumference and blood pressure were measured using standard procedures. Pulse pressure was calculated as systolic minus diastolic blood pressure and averaged across two readings. Associations were examined using Spearman correlation, sex-stratified summaries and heteroskedasticity-robust linear regression.

Results: The mean age was 8.5 ± 1.8 years, and 216 (53.7%) participants were girls. The mean neck circumference was 26.8 ± 1.8 cm, and the mean pulse pressure was 39.1 ± 7.7 mmHg. Boys had a statistically higher mean neck circumference than girls, although the absolute difference was small (27.1 ± 1.6 cm versus 26.7 ± 1.9 cm; $t = 2.20$; $p = 0.028$). Mean pulse pressure was 38.9 ± 7.9 mmHg in boys vs. 39.3 ± 7.5 mmHg in girls ($p = 0.584$). Neck circumference correlated positively with pulse pressure overall ($r = 0.428$; $p < 0.001$), in boys ($r = 0.431$; $p < 0.001$) and in girls ($r = 0.435$; $p < 0.001$). In the fully adjusted model, each 1.0 cm increase in neck circumference was associated with 1.50 mmHg higher pulse pressure (95% Confidence Interval 0.81 to 2.19; $p < 0.001$). The association between neck circumference and pulse pressure did not differ significantly by sex (interaction $p = 0.456$).

Conclusion: Increasing neck circumference was independently associated with higher pulse pressure. This low-cost measurement may support school-based cardiovascular risk screening when used alongside routine blood pressure and body-size assessment.

Keywords: *Anthropometry, Blood pressure, Cardiometabolic Risk, Nigeria, Obesity, School-aged children.*

Introduction

Cardiovascular disease usually becomes clinically visible in adulthood, but its antecedents often begin much earlier. Childhood and adolescent blood pressure, adiposity and other cardiometabolic risk profiles can track across the

life course and have been associated with later vascular injury, adult hypertension and cardiovascular events.¹⁻⁵ For paediatric practice, it is not too early to start risk recognition in childhood. Rather, it is an important period for identifying measurable risk markers and for

promoting healthy behaviours before vascular risk becomes entrenched.

Pulse pressure, defined as systolic blood pressure minus diastolic blood pressure, reflects the pulsatile component of arterial load. In children, pulse pressure must be interpreted with caution because growth, stroke volume, arterial compliance, body size and wave reflection all influence measured values.⁵⁻⁷ Even so, wider pulse pressure should not automatically be dismissed as a physiological entity. Earlier work has linked paediatric pulse pressure with obesity-related haemodynamic change as well as later subclinical vascular damage, suggesting that it may provide a practical, though imperfect, signal of early vascular stress.^{7,8}

Neck circumference is a convenient anthropometric marker of upper-body adiposity. Unlike waist-based indices, it can be measured quickly, requires minimal disturbance of clothing, is less affected by post-prandial abdominal distension and may be more acceptable in school screening programmes.⁹⁻¹² Its usefulness is prominent in low-resource paediatric settings where height boards, calibrated scales and waist measurement protocols may not always be readily available or consistently implemented. Evidence from systematic reviews and paediatric studies shows that larger neck circumference is associated with elevated blood pressure, excess adiposity, metabolic risk indicators and cardiometabolic clustering in children and adolescents.⁹⁻¹⁴

The scientific link between neck circumference and arterial pressure is biologically plausible. Upper-body fat accumulation is metabolically active and has been associated with insulin resistance, inflammatory signalling, sympathetic nervous system activation, altered renin-angiotensin-aldosterone system activity, endothelial dysfunction and vascular stiffness.⁹⁻

¹⁴ These mechanisms may increase systolic load,

alter arterial compliance and affect wave reflection, thereby widening pulse pressure. Neck circumference may therefore capture a dimension of body-fat distribution that is not fully conveyed by BMI only.

African and Nigerian data on simple paediatric cardiovascular screening markers remain limited. Recent African reviews have highlighted the need for earlier detection of blood pressure-related risk in childhood, but most available studies focus on systolic and diastolic blood pressure rather than pulse pressure.¹⁵ In Nigeria, anthropometric indices have been related to cardiovascular parameters among primary-school pupils, but the specific relationship between neck circumference and pulse pressure has been less clearly described.¹⁶ This gap matters because schools and primary-care settings need inexpensive, reproducible screening tools that can be used without specialist equipment.

The research question in this study was whether neck circumference is independently associated with average pulse pressure among school-aged children in Ibadan after accounting for age, sex, BMI, socioeconomic position and school type. We hypothesised that larger neck circumference would be associated with wider pulse pressure, and that this association would persist after adjustment for general body size. The objectives of the study were to describe age- and sex-specific patterns of neck circumference and pulse pressure, examine the correlation between neck circumference and pulse pressure, and estimate the adjusted association between neck circumference and pulse pressure in this school-based sample.

Methods

Study design and setting

This was a school-based cross-sectional study conducted in Ibadan North Local Government Area, Oyo State, Nigeria. Ibadan North is an

urban setting that includes densely built metropolitan neighbourhoods and suburban communities. The source study examined apparently healthy primary-school children aged 5-12 years in public and private schools. For this study, the analytic focus was the relationship between neck circumference and pulse pressure, with emphasis on effect-size estimation and confounder-adjusted modelling.

Ethical considerations

The study protocol was reviewed and approved by the Oyo State Ministry of Health Ethical Review Committee (approval number AD 13/479/734). Permission to conduct the study was obtained from the relevant education authorities and school heads. Written informed consent was obtained from parents or caregivers, and age-appropriate assent was obtained from participating children aged 5-12 years before data collection.

Sample size and sampling technique

The minimum sample size in the source study was based on the expected correlation between neck circumference and blood pressure indicators from previous paediatric literature. Using the Bonett and Wright approach for sample size estimation for correlation studies, the larger correlation-based requirement was approximately 180 participants.^{9,17} Because sex-stratified analyses were planned *a priori*, this number was doubled to 360 to provide adequate representation of boys and girls. Allowing for approximately 10% non-response or incomplete measurement increased the target sample to about 400 children. The final analytic sample comprised 402 children with complete neck circumference and pulse pressure data.

A multistage stratified random sampling approach was used. Ibadan North Local

Government Area has 12 geopolitical wards. In the first stage, one public and one private primary school were randomly selected from each ward, making 24 schools in all. In the second stage, eligible pupils were listed within each selected school, and the number to be recruited from each school was allocated proportionately according to school enrolment size. In the third stage, pupils were stratified by age and sex within schools and selected randomly from school registers until the required allocation was reached. The sampling process is summarised in Figure 1.

Study participants

Eligible participants were boys and girls aged 5-12 years enrolled in the selected primary schools, whose parents or guardians provided written consent and who gave age-appropriate assent. Children with neck swelling were excluded because swelling could distort neck measurement. Children absent on the day of data collection or reported to be on medication were also excluded.

Data collection

Data were collected by investigators and trained assistants during school visits, using a structured questionnaire and direct measurements.

Measurements and study variables

Height, weight and BMI were included because the study needed to separate the specific association of neck circumference from general body size. Height was measured barefoot to the nearest 0.1 cm with a portable stadiometer, with the child standing erect and the head positioned in the Frankfort horizontal plane. Weight was measured to the nearest 0.1 kg with a digital scale checked regularly during fieldwork. BMI was calculated as weight in kilograms divided by height in metres squared.

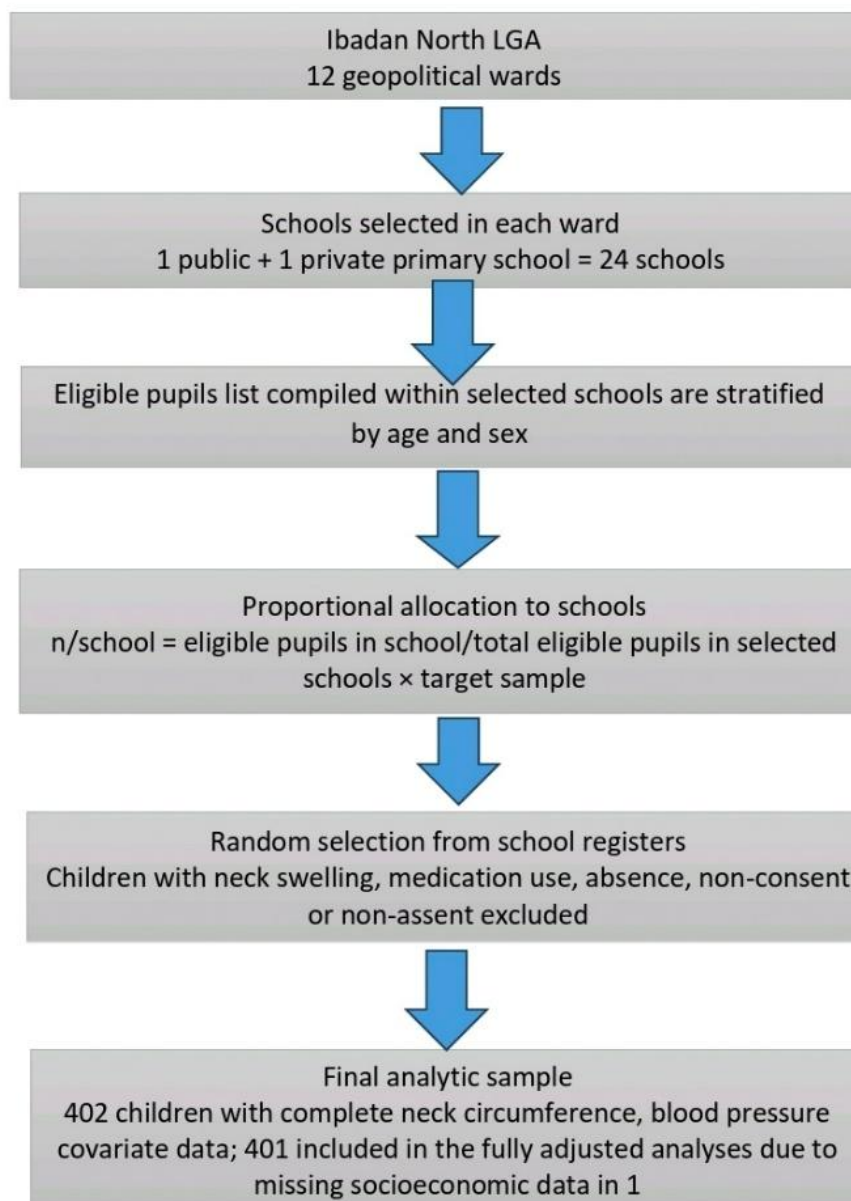


Figure 1: Sampling flow for selection of school-aged children in Ibadan North Local Government Area.

We measured neck circumference with a non-elastic measuring tape in the horizontal plane at the level of the thyroid cartilage while the child stood upright, looked forward, and kept the shoulders relaxed.^{11, 12} Socioeconomic status was determined by the Oyediji composite score derived from parental education and occupation; lower scores indicate higher socioeconomic class,

so a median score of 3.25 lies within the middle socioeconomic range.¹⁸ School type was classified as public or private.

Blood pressure was measured twice during the school assessment, after the child had been seated quietly, using a Medtech Novacheck BP-18 fully automatic digital upper-arm blood-pressure

monitor (Oscillometric method; Medtech Life Pvt. Ltd., India) fitted with an appropriately sized paediatric cuff. Measurements were taken on the right arm supported at heart level, with the child instructed to remain still during measurement. Pulse pressure was calculated for each reading as systolic blood pressure minus diastolic blood pressure. The primary outcome was average pulse pressure, derived as the mean of the two pulse pressure values, to reduce random within-child measurement variability. Pulse pressure was analysed as a continuous haemodynamic outcome because paediatric reference standards are well established for systolic and diastolic blood pressure but less standardised for pulse pressure.⁵⁻⁷ Neck circumference was treated as the main explanatory variable. BMI was retained as the principal adiposity covariate in the multivariable models to account for general body size while avoiding unnecessary over-adjustment from entering several closely correlated anthropometric measures simultaneously.

Statistical analysis

Data were analysed using Python version 3.11 with pandas, scipy and statsmodels libraries. Age, neck circumference, BMI and average pulse pressure were summarised as mean $\pm$ standard deviation because they were approximately continuous variables of primary interest. Socioeconomic score was summarised as median and interquartile range. Sex, school type, ethnic group and socioeconomic class were summarised as frequencies and percentages.

Sex differences in mean neck circumference and average pulse pressure were assessed with independent-samples *t* tests. Differences in categorical characteristics by sex were assessed with Chi-Square tests. Age-specific variation in neck circumference and pulse pressure was examined using One-way Analysis of Variance. Bivariate associations between pulse pressure and continuous variables were examined using

Spearman correlation coefficients overall and by sex. To quantify the independent relationship between neck circumference and pulse pressure, three ordinary least squares regression models with HC3 robust standard errors were fitted. Model 1 was unadjusted. Model 2 adjusted for age and sex. Model 3 adjusted for age, sex, body mass index, socioeconomic score and school type. A sex-by-neck-circumference interaction term was tested to assess effect modification by sex. In supplementary analyses, high pulse pressure was defined as an average pulse pressure above the 95th percentile within the study-specific age- and sex-stratified distribution. Logistic regression models were fitted using the same 401-participant complete-case sample; the adjusted model included age, sex, body mass index, socioeconomic score and school type. All tests were two-sided, and statistical significance was set at $p < 0.05$.

Results

The sampling and selection process is summarised in Figure 1. The analytic sample comprised 402 children with complete neck circumference and blood-pressure data; 401 had complete covariate data for the fully adjusted models. The mean age of the participants was 8.5 ± 1.8 years, and 216 (53.7%) were girls. As shown in Table I, slightly more than half of the children (226; 56.2%) attended private schools, and most were Yoruba (320; 79.6%). The median socioeconomic score was 3.25, with an interquartile range of 2.50 to 4.50. This score corresponds approximately to the middle socioeconomic stratum on the Oyedegbe scale, indicating that the study population was predominantly middle class, although 116 (28.9%) belonged to the low socioeconomic group.

Boys had a statistically higher mean neck circumference than girls, although the absolute difference was small (27.1 ± 1.7 cm vs. 26.7 ± 1.9

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cm; $t = 2.20$, $p = 0.028$). The mean pulse pressure was similar in boys and girls (38.9 ± 7.9 mmHg in boys versus 39.3 ± 7.5 mmHg in girls; $t = -0.55$, $p = 0.584$).

Age-specific patterns of neck circumference and pulse pressure are presented in Table II. Neck circumference increased progressively with age, from 24.9 ± 0.9 cm at 5 years to 27.7 ± 1.4 cm at 12

years. Mean pulse pressure also varied by age, rising from 33.9 ± 5.7 mmHg at 5 years to a peak of 42.1 ± 7.3 mmHg at 10 years before stabilising at older ages. Overall, sex differences within age groups were modest and inconsistent. The age- and sex-specific 5th, 50th and 95th percentiles of average pulse pressure are provided in Supplementary Table SI.

Table I: Characteristics of the participants distributed according to sex

Characteristics	All participants (n = 402)	Boys (n=186)	Girls (n=216)	Test statistic	p-value
Age, years, mean $\pm$ SD	8.5 ± 1.8	8.5 ± 1.8	8.5 ± 1.8	$t = -0.32$	0.748
Private school, n (%)	226 (56.2)	110 (59.1)	116 (53.7)	$\chi^2 = 1.20$	0.273
Public school, n (%)	176 (43.8)	76 (40.9)	100 (46.3)		
Yoruba ethnic group, n (%)	320 (79.6)	154 (82.8)	166 (76.9)	$\chi^2 = 2.18$	0.140
Other ethnic groups, n (%)	82 (20.4)	32 (17.2)	50 (23.1)		
High socioeconomic class, n (%)	41 (10.2)	16 (8.6)	25 (11.6)	$\chi^2 = 3.94$	0.140
Middle socioeconomic class, n (%)	245 (61.0)	123 (66.1)	122 (56.5)		
Low socioeconomic class, n (%)	116 (28.9)	47 (25.3)	69 (31.9)		
Neck circumference, cm, mean $\pm$ SD	26.8 ± 1.8	27.1 ± 1.6	26.7 ± 1.9	$t = 2.20$	0.028
Average pulse pressure, mmHg, mean $\pm$ SD	39.1 ± 7.7	38.9 ± 7.9	39.3 ± 7.5	$t = -0.55$	0.584

Table II: Age- and sex-specific neck circumference and average pulse pressure

Age (years)	n	Neck circumference			Average Pulse Pressure		
		All	Boys	Girls	All	Boys	Girls
5	22	24.9 ± 0.9	25.2 ± 0.9	24.8 ± 0.9	33.9 ± 5.7	33.4 ± 6.6	34.2 ± 4.5
6	41	25.5 ± 1.2	25.8 ± 1.2	25.0 ± 1.0	36.7 ± 7.9	36.6 ± 8.5	37.0 ± 6.8
7	64	26.5 ± 1.6	26.9 ± 1.0	26.3 ± 1.7	38.2 ± 7.7	40.8 ± 8.1	37.0 ± 7.3
8	71	26.6 ± 1.4	26.9 ± 1.1	26.3 ± 1.5	38.6 ± 7.2	38.7 ± 6.3	38.4 ± 7.9
9	89	27.5 ± 2.2	27.5 ± 1.9	27.5 ± 2.4	39.3 ± 8.0	38.3 ± 8.3	40.4 ± 7.7
10	57	27.6 ± 1.9	28.0 ± 1.8	27.4 ± 1.9	42.1 ± 7.3	42.0 ± 7.6	42.3 ± 7.1
11	33	27.3 ± 1.2	27.2 ± 1.1	27.3 ± 1.2	41.3 ± 6.6	41.0 ± 7.7	41.5 ± 6.1
12	25	27.7 ± 1.4	27.8 ± 0.8	27.6 ± 1.8	41.3 ± 7.9	43.4 ± 7.4	38.2 ± 8.0
Overall	402	26.8 ± 1.8	27.1 ± 1.7	26.7 ± 1.9	39.1 ± 7.7	38.9 ± 7.9	39.3 ± 7.5

Table S1 (Supplementary): Age- and sex-specific 5th, 50th and 95th percentiles of average pulse pressure

Age (years)	Boys 5 th	Boys 50 th	Boys 95 th	Girls 5 th	Girls 50 th	Girls 95 th
5	24.0	34.5	40.9	27.7	34.5	40.1
6	21.8	36.0	49.9	27.0	37.5	45.9
7	29.5	41.5	52.5	26.0	36.0	49.4
8	29.2	38.2	49.1	27.5	35.0	53.5
9	24.2	38.0	53.0	29.0	40.0	54.1
10	31.7	41.5	51.8	32.5	41.5	56.2
11	29.0	41.8	51.8	33.5	40.5	49.5
12	27.7	36.8	48.5	35.7	42.5	55.1

Values are percentiles of average pulse pressure in mmHg within each age-by-sex stratum

In bivariate analysis, average pulse pressure correlated positively with age, weight, height, body mass index and neck circumference (Table III). The strongest correlation observed was between neck circumference and pulse pressure, with a Spearman correlation coefficient of 0.428 in the overall sample ($p < 0.001$). The association was similar when examined separately by sex: $r = 0.431$ among boys and $r = 0.435$ among girls, with $p < 0.001$ in each case. The scatter plot in Figure 2 illustrates this positive relationship between neck circumference and average pulse pressure, with broadly similar upward trends in boys and girls.

In the robust linear regression analyses shown in Table IV, neck circumference remained positively associated with average pulse pressure across all model specifications. In the unadjusted model, every 1 cm increase in neck circumference was associated with a 1.76 mmHg higher pulse pressure (95% confidence interval 1.28 to 2.25; $p < 0.001$). After adjustment for age and sex, the

corresponding increase was 1.64 mmHg per cm (95% Confidence Interval 1.10 to 2.18; $p < 0.001$). In the fully adjusted model, which included age, sex, body mass index, socioeconomic score and school type, every 1 cm increase in neck circumference remained associated with a 1.50 mmHg higher pulse pressure (95% Confidence Interval 0.81 to 2.19; $p < 0.001$). Public-school attendance was also independently associated with higher pulse pressure in the fully adjusted model (β 2.89 mmHg, 95% confidence interval 0.13 to 5.65; $p = 0.040$). There was no evidence that the association between neck circumference and pulse pressure differed by sex (sex-by-neck circumference interaction $p = 0.456$).

In a supplementary analysis that defined high pulse pressure as a value above the age- and sex-specific 95th percentile, increasing neck circumference was also associated with higher odds of high pulse pressure in both unadjusted and adjusted logistic models (Supplementary Table S2).

Table III: Spearman correlations between pulse pressure and age or anthropometric indices

Variables	Boys		Girls		Overall	
	r	p	R	p	R	P
Age, years	0.147	0.045	0.333	<0.001	0.244	<0.001
Neck circumference, cm	0.431	<0.001	0.435	<0.001	0.428	<0.001
Weight, kg	0.334	<0.001	0.435	<0.001	0.390	<0.001
Height, cm	0.222	0.002	0.427	<0.001	0.333	<0.001
Body Mass Index, kg/m ²	0.406	<0.001	0.282	<0.001	0.338	<0.001

r denotes the Spearman correlation coefficient

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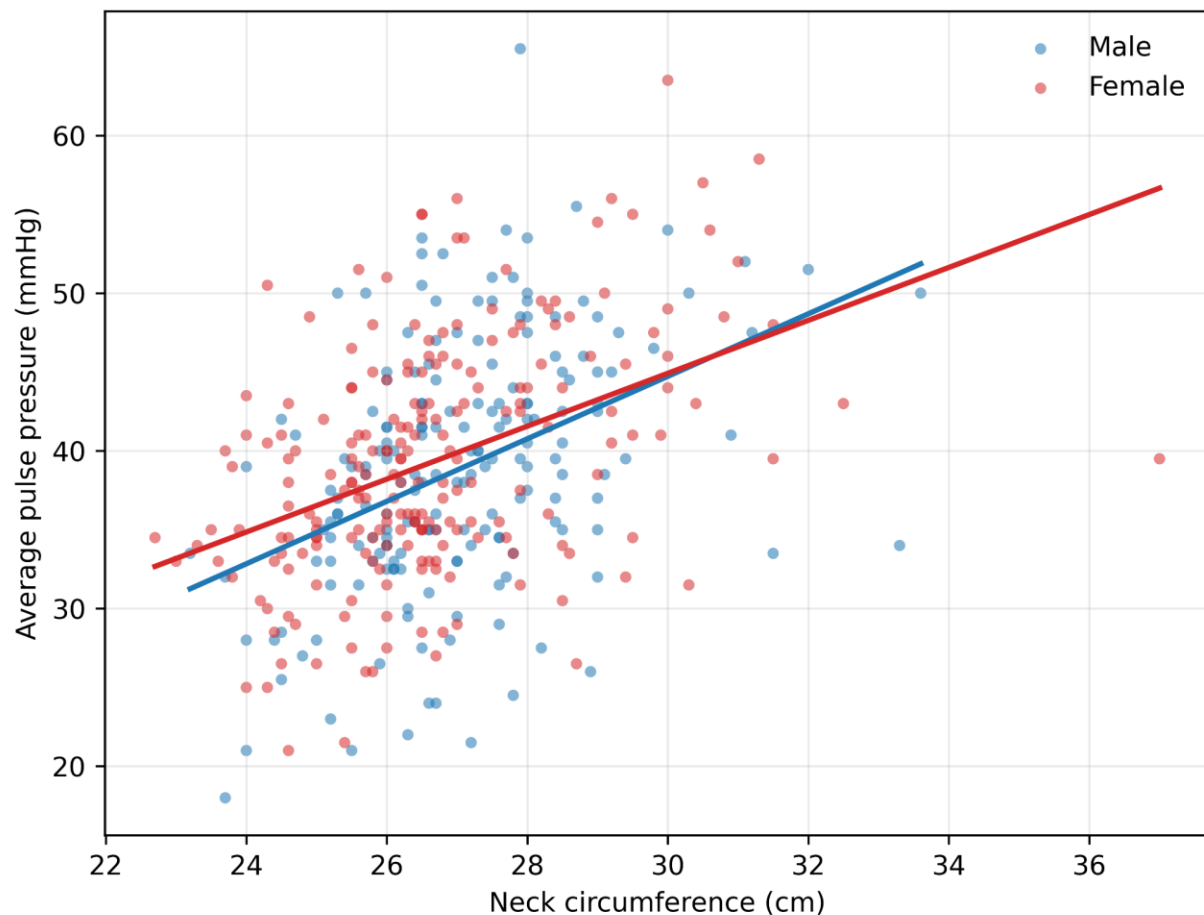


Figure 2: Scatter plot of neck circumference and average pulse pressure distributed by sex
Points represent individual children; fitted lines show the sex-specific linear trend.

Table IV: Heteroskedasticity-robust linear regression models for average pulse pressure

Model	Covariates	β for neck circumference (mmHg per cm)	Robust SE	t	95% Confidence Interval	p-value
Model 1	Unadjusted	1.76	0.25	7.08	1.28 to 2.25	<0.001
Model 2	Age- and sex adjusted	1.64	0.27	5.96	1.10 to 2.18	<0.001
Model 3	Age, sex, body mass index, socioeconomic score and school type	1.50	0.35	4.29	0.81 to 2.19	<0.001
Model 3 additional covariate	Public school attendance versus private school	2.89	1.41	2.06	0.13 to 5.65	0.040

β denotes the regression coefficient in mmHg. Model 3 additionally showed no statistically significant neck circumference-by-sex interaction ($p=0.456$).

Table S2 (Supplementary): Logistic models for high pulse pressure, defined as a value above the age- and sex-specific 95th percentile

Model	N	OR per 1 cm increase in neck circumference	95% CI	p-value
Unadjusted	401	1.33	1.10 to 1.61	0.003
Adjusted	401	1.49	1.04 to 2.15	0.030

Both models used the same complete-case dataset. One participant with an invalid socioeconomic score (recorded as 999) was excluded.

High pulse pressure is defined within each age-by-sex stratum as an average pulse pressure above the 95th percentile of the study distribution. The adjusted model included age, sex, body mass index, socioeconomic score and school type.

Discussion

This school-based study demonstrated a positive association between neck circumference and pulse pressure among children aged 5-12 years in Ibadan. The relationship was present in the whole sample, similar in boys and girls, and remained statistically significant after adjustment for age, sex, BMI, socioeconomic position and school type. The size of the association is clinically interpretable: every additional centimetre of neck circumference corresponded to about 1.5 mmHg higher pulse pressure in the fully adjusted model. This suggests that neck circumference was not merely reflecting larger body size but may also capture a distribution of adiposity relevant to pulsatile haemodynamic load in childhood.

The findings are consistent with the broader paediatric literature linking neck circumference with blood pressure and cardiometabolic risk. Systematic reviews and primary studies have reported that larger neck circumference is associated with elevated blood pressure, excess adiposity, metabolic risk indicators and cardiometabolic clustering in children and adolescents.⁹⁻¹⁴ Much of that evidence has focused on systolic blood pressure, diastolic blood pressure, hypertension or metabolic syndrome. The present study adds a more specific haemodynamic perspective by showing that neck circumference is also related to pulse pressure in a Nigerian school-aged sample.

The biological plausibility of this association is strong. Neck circumference reflects upper-body subcutaneous fat accumulation, which may be metabolically active and associated with insulin resistance, inflammatory signalling, autonomic imbalance and vascular dysfunction.⁹⁻¹⁴ In growing children, such mechanisms may influence pulse pressure through higher systolic load, increased stroke volume, altered arterial compliance or wave reflection. Cross-sectional data cannot confirm the mechanism, but persistence of the association after adjustment for body mass index suggests that neck circumference may provide information beyond total body size.

The age-related rise in neck circumference and pulse pressure also deserves attention. Some increase in these measures would be expected during growth, but the pattern reinforces the need to interpret childhood blood pressure within developmental context rather than in isolation.⁵⁻⁷ Childhood pulse pressure should not be regarded as trivial because longitudinal evidence suggests that higher childhood pulse pressure may be associated with subclinical vascular damage later in life.⁸ The higher pulse pressure observed among public-school pupils in the fully adjusted model should be interpreted cautiously. School type is likely acting as a contextual marker rather than a direct causal exposure. It may reflect unmeasured differences in household resources, diet, physical activity opportunities, psychosocial

stress, commuting patterns or school-level environments. The finding is useful because it suggests that haemodynamic differences in children may be shaped by social and environmental context as well as by individual adiposity.

This study has several strengths. It is based on a school sample rather than a clinic population, improving relevance to paediatric public health and school health practice. Anthropometric and blood pressure data were measured directly using standard procedures. Pulse pressure was derived from two blood pressure readings rather than a single measurement, and the regression models used robust standard errors to reduce dependence on homoskedasticity assumptions.

The limitations are also important. The cross-sectional design precludes causal inference; we cannot determine whether larger neck circumference precedes wider pulse pressure or merely coexists with it. The study was conducted within one local government area, which may limit wider generalisability. Pubertal staging, dietary exposures, physical activity, sleep-related factors, family cardiovascular history and school-level identifiers for multilevel modelling were not available in the analytic file. Finally, pulse pressure in childhood does not yet have the same standardised clinical interpretability as systolic or diastolic blood pressure.

Despite these limitations, the findings remain relevant. The measurement of neck circumference is inexpensive, rapid, non-invasive and feasible in busy or resource-limited settings. Used alongside routine blood pressure and body-size assessment, it may help identify children who merit closer cardiometabolic evaluation. Longitudinal Nigerian and multicentre African studies are needed to test predictive performance, establish age- and sex-specific reference ranges and determine whether neck circumference adds meaningful screening value beyond existing anthropometric tools.

Conclusion

Increasing neck circumference was independently associated with higher pulse pressure among school-aged children in Ibadan. Every additional centimetre of neck circumference corresponded to about 1.5 mmHg higher pulse pressure after adjustment for age, sex, BMI, socioeconomic position and school type. Neck circumference should not be used as a stand-alone diagnostic marker, but it may be useful as a low-cost component of school-based cardiovascular risk screening when combined with routine blood pressure measurement and body-size assessment.

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