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RESEARCH ARTICLE

Evaluating modifiable hypertension risk in Nigerian adults—The Nigerian diet risk score

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Abstract

Aims: Our study aimed to derive and validate a diet risk score for clinical use in Nigeria to screen for hypertension risk and evaluate its association against a panel of cardiovascular biomarkers.

Methods: The Nigerian dietary screening tool was used to collect dietary intake data from 151 participants visiting the River State University Teaching Hospital, Port Harcourt, Nigeria, for routine medical care. Blood samples were collected from a subsample ($n = 94$) for biomarker assessment. Multiple logistic regression was used to derive the Nigerian diet risk score for hypertension. Internal validation of the Nigerian diet risk score for hypertension was performed using measures of discrimination and calibration. Mediation analysis was used to evaluate the biomarker-mediated effects of the diet risk score for hypertension on hypertension. All statistical analyses were performed in R.

Results: Each one-point increment in Nigerian diet risk score (on a scale of 0 to 30) was associated with a twofold increase in odds of hypertension (odds ratio: 2.04, 95% confidence interval [CI]: 1.16, 3.58, $p = 0.01$), with the highest score associated with >18-fold increased odds of hypertension, compared to lowest Nigerian diet risk score for hypertension. The score demonstrated good discrimination (area under the curve: 0.92, 95% CI: 0.80, 1.00) with a high sensitivity (0.85) and specificity (0.94). Additionally, mediation analysis suggested that the association between Nigerian diet risk score for hypertension and blood pressure is partly explained by shared biological pathways that mediate cholesterol, triglycerides, LDL-C, CRP and homocysteine levels.

Conclusion: The resulting Nigerian diet risk score for hypertension is a valuable tool for clinicians to identify individuals at risk of hypertension, and will advance community efforts in the prevention and management of hypertension in Nigeria.

KEYWORDS
biomarkers, clinical practice, diet risk score, hypertension, mediation analysis

INTRODUCTION

Cardiovascular diseases account for 31% of all global deaths, the majority (80%) of which are associated with hypertension [1, 2]. As of 2019, the African region reported the highest prevalence of hypertension (35.5%), with more than one in three adults (i.e., over 150 million) [3, 4]. Unfortunately, unlike Western countries that have reported a 6%–11% decline in hypertension since 2010 [5, 6], the prevalence of hypertension in West African countries has increased [7]. In Nigeria, hypertension increased from 11.2% to 36.1% between 1990 and 2019 [3, 7]. Consequently,

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a 53% proportional increase in mortality from hypertension has been observed in Nigeria (13.4 per 100,000 in 1990 to 20.5 per 100,000 in 2015 age-adjusted death rate) [8]. These data underline the urgent need for targeted prevention and management strategies.

Dietary habits, including high intakes of salt and processed food, including meat and low intakes of vegetables, fruits, dietary fibre and nutrients such as potassium and omega-3 fatty acids, are estimated to account for 9%–17% of cases of hypertension worldwide [1, 9, 10]. In West Africa, the SIREN study in Nigeria and Ghana confirmed that diets rich in whole grains and fruit drinks were associated with lower odds of hypertension, whereas higher consumption of processed foods was associated with higher odds of hypertension [11]. Furthermore, recent meta-analyses of 31 observational studies with more than 48,000 participants suggest that staple foods in West Africa, including Nigeria, are important mediators of hypertension risk [10]. Therefore, strategies to improve dietary habits offer a key opportunity to modify hypertension risk in West Africa, including Nigeria.

Risk stratification tools assess the combined impact of various disease risk factors to estimate an individual's overall risk. Such tools can improve risk prediction compared to clinician assessment alone and empower patients to minimise their level of risk [12]. The Framingham and INTERHEART scores are well-known cardiovascular disease risk tools for large, diverse populations, and the DASH, MedX and Healthy Eating Indices correlate well with hypertension [13–15]. The Framingham and INTERHEART both consider dietary patterns or key foods, alongside key health and lifestyle parameters (e.g., age, diabetes-status, smoking, body mass index [BMI]) but they do not distinguish food groups or consider cooking methods that can modify the nutrition and caloric content of food and the 'weight' of that food group to hypertension risk. As such, such tools can be less accurate in populations with unique dietary habits or cultural practices, as observed in Nigeria [10, 16, 17]. For instance, the SPICES multi-country study ($n = 9309$ participants in England, France, Belgium, South Africa and Uganda) demonstrated that the importance of INTERHEART's study components (e.g., diet, age, smoking, etc.) vary significantly ($p < 0.001$) between continents. In sub-Saharan African countries, such as Nigeria, diet was approximately three-times more important for predicting hypertension risk, compared to European cohorts [18]. This suggests that a dietary risk score that considers Nigerian culture is likely to be more accurate and better support healthcare professionals to empower patients to manage and, consequently, lower the prevalence of hypertension.

Therefore, this study aimed to: (i) derive and test the utility of a dietary risk score—Nigerian Diet Risk Score (NiDRS) for hypertension in Nigeria and (ii) evaluate the NiDRS alongside a panel of clinical predictors and biomarkers for hypertension. Our goal is for the NiDRS to be used by clinicians, patients and researchers across Nigeria and other West African countries to: (i) facilitate discussions of dietary habits and offer personalised dietary counselling for patients at risk or with hypertension with an aim to improve cardiovascular health within clinical settings; and (ii) empower Nigerians to take an active role in the prevention and management of hypertension.

MATERIALS AND METHODS

Study design and setting

This study used a cross-sectional design of consenting adults visiting the Rivers State University Teaching Hospital (RSUTH) in Port Harcourt, Nigeria, for routine medical care. This hospital was selected as it is a centrally located referral centre for a large region, including Rivers State and the neighbouring Bayelsa, Abia and Akwa-Ibom States, with diverse patient demographics. The study protocol was reviewed and approved by both the RSUTH, Nigeria and the University of Leeds ethics committees. Our detailed study protocol has also been published [19].

Study population

A total of 151 patients were recruited over 3 weeks in December 2023 at the Internal Medicine and Family Medicine Department outpatient clinics of RSUTH, using a non-probability convenience sampling method, using posters and flyers placed within the hospital premises and morning outpatient clinic briefing sessions. We excluded individuals aged <18 and >70 years, pregnant or breastfeeding women, those intending pregnancy, individuals diagnosed with cancer, diabetes, renal failure, or recent CVD and stroke, individuals on dietary restrictions or with recent dietary changes, and those enrolled in other studies. Eligible participants received a participant information sheet (PIS) and consent form to review. Written informed consent was obtained from all participants prior to study enrolment. To minimise bias, the hypertension state of participants was blinded, and the study adhered to *STROBE* guidelines for reporting observational studies [20].

Clinical assessment

Participants' height, weight, waist circumference, and resting blood pressure were measured by trained clinical staff using standardised protocols. Height was measured to the nearest 0.1 cm and weight to the nearest 0.1 kg using a standard stadiometer (model number: DG2301, China). Waist circumference was measured to the nearest 0.1 cm at the midpoint between the bottom of the rib cage and above the top of the iliac crest. The average of three resting blood pressure measurements was obtained on the dominant arm using an automated mercury sphygmomanometer (model number: ZK-BB68, Shenzhen, China). Mean arterial pressure (MAP) was calculated from the average value of the systolic and diastolic blood pressure using the formula (MAP = diastolic

blood pressure + 1/3 [systolic blood pressure − diastolic blood pressure]). BMI was calculated by dividing their weight in kilogrammes by their height in metres squared.

Dietary assessment

The Nigerian dietary screening tool (NiDST), a validated 25-item semi-quantitative food frequency questionnaire (FFQ) designed for a Nigerian population, was used to quantify participants' usual dietary intake over the past month [21–23]. The tool consists of 25 questions on 23 food groups, with two additional questions on salt and seasonings. For each food group, participants reported the frequency of consumption over the past month, with response options ranging from 'rarely or never', '1–2 times/week', '3–5 times/week', 'daily', '1–2 times/day', '3–4 times/day' and '5+ times/day' (Table S1).

Outcome measures

MAP was selected as our primary outcome measure because of its performance to more accurately predict hypertension compared to systolic or diastolic blood pressure separately [24, 25]. In addition, a subgroup of participants ($n = 91$) provided 10 mL of fasting blood samples. Serum samples underwent analysis for cardiovascular biomarkers: low-density lipoprotein cholesterol (LDL-C), high-density lipoprotein cholesterol (HDL-C), very low-density lipoprotein cholesterol (VLDL-C), total cholesterol (TC), triglycerides (TG), serum electrolytes (e.g., sodium, potassium, calcium and magnesium) and inflammatory markers (e.g., C-reactive protein [CRP] and homocysteine) according to Clinical Chemistry Laboratory protocol at RSUTH [26–29]. LDL-C and VLDL-C were calculated using the Friedewald equation [30]. We also investigated the association between the NiDRS and atherogenic lipid profile indices [31]: such as the Atherogenic Index of Plasma (AIP: *log*[TG/HDL-C]), Atherogenic Coefficient (AC: [TC − HDL-C]/HDL-C), Castelli Risk Index I (CRI-I: TC/HDL-C), Castelli Risk Index (CRI-II: LDL-C/HDL-C) and total HDL-C cholesterol ratio (THDL: HDL-C/[TC − HDL-C]) [32–35].

Statistical analysis

The normality of continuous variables was assessed with a visual inspection of the histogram, with non-normal distributions confirmed using the Shapiro–Wilk or Kolmogorov–Smirnov tests [36, 37]. Descriptive statistics were presented as mean ± standard deviation (SD), median, and interquartile range (IQR) for continuous data and counts (n) and percentage (%) for categorical data. Associations between variables were examined using chi-squared tests for categorical data, paired student's t-tests for normally distributed continuous data, and Wilcoxon-ranked signed text for non-normally distributed continuous data. The analyses of the data were stratified by hypertensive (with either a systolic blood pressure ≥140 or a diastolic blood pressure ≥90 mmHg) and

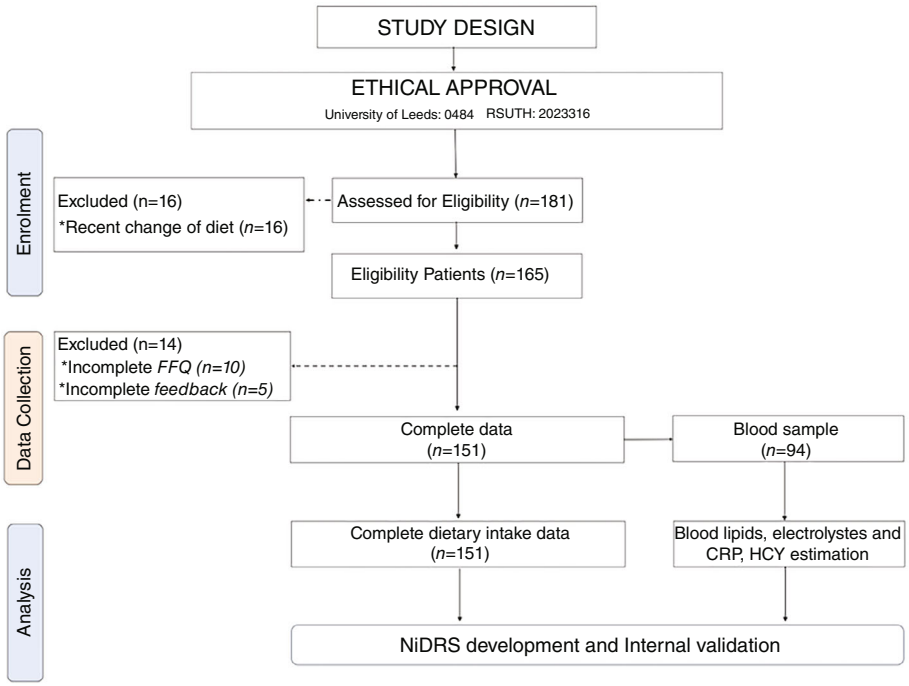

FIGURE 1 Participant selection flowchart through completion of the FFQ (the Nigerian dietary screening tool; NiDST) and biomarkers estimation. CRP, C-reactive protein; NiDRS, Nigerian diet risk score; HCY, homocysteine, blood lipids (such as triglyceride, total cholesterol, low-density lipoprotein, high-density lipoproteins, very low-density lipoprotein) and electrolytes (such as sodium, potassium, calcium, and magnesium).

non-hypertensive (with either a systolic blood pressure <140 or a diastolic blood pressure <90 mmHg).

We developed a diet risk score from the NiDST intake data using methods similar to Framingham and INTERHEART [38, 39]. Briefly, participants were randomly assigned to derivation set (80%) or validation set (20%) [40]. Adjusted multiple variable models were constructed in the derivation set, with the beta-coefficients used as 'weights' for each food associated with hypertension. The weights (rounded to nearest integer), were then tested in the validation set by multiplying the weight of each food group by participant reported intake. The products for all foods for each participant were then summed to give the NiDRS for hypertension and tested against MAP and hypertension status.

A 2/3 sample quantile to convert the total NiDRS set into the high versus low NiDRS risk category. The predictive performance of the NiDRS was assessed by receiver operating characteristic (ROC) curve [41], the Hosmer-Lemeshow goodness-of-fit test and Brier score [42, 43], to evaluate accuracy, precision, sensitivity and specificity and determine the threshold cut-offs for 'low' and 'high' risk categories. The clinical utility of the NiDRS was also evaluated using the decision curve analysis (DCA) [44–47]. Finally, we

TABLE 1 Sociodemographic and clinical characteristics of study participants ($n = 151$).

Characteristics	Overall ($n = 151$)	Hypertensive ($n = 88$, 58.3%)	Non-hypertensive ($n = 63$, 41.7%)	*p-value
Sex, *n* (%)				**0.010**
Male	75 (49.7)	52 (59.1)	23 (36.5)	
Female	76 (50.3)	36 (40.9)	40 (63.5)	
Age (years)	44.4 ± 11.1	46.0 ± 10.2	42.1 ± 12.2	0.098
Education, *n* (%)				0.472
No formal	1 (0.6)	1 (1.1)	0 (0)	
Primary	26 (17.2)	14 (15.9)	12 (19.1)	
Secondary	62 (41.1)	40 (45.5)	22 (34.9)	
Tertiary	62 (41.1)	33 (37.5)	29 (46.0)	
Marital status, *n* (%)				0.072
Divorced	3 (2.0)	2 (2.3)	1 (1.6)	
Married	119 (78.8)	75 (85.2)	44 (69.8)	
Single	18 (11.9)	6 (6.8)	12 (19.0)	
Widowed	11 (7.3)	5 (5.7)	6 (9.5)	
Employment, *n* (%)				0.057
Employed	25 (16.6)	14 (15.9)	11 (17.5)	
Homemaker	1 (0.6)	0 (0)	1 (1.6)	
Retired	9 (6.0)	7 (8.0)	2 (3.2)	
Self-employed	103 (68.2)	63 (71.6)	40 (63.5)	
Student	8 (5.3)	1 (0.6)	7 (11.1)	
Unemployed	5 (3.3)	3 (3.4)	2 (3.2)	
Family history of HTN, *n* (%)	34 (22.5)	26 (29.5)	8 (12.7)	
Physical activity level, *n* (%)				0.542
Active	23 (15.2)	12 (13.6)	11 (17.5)	
Moderately active	15 (9.9)	7 (8.0)	8 (12.7)	
Moderately inactive	41 (27.2)	27 (30.7)	14 (22.2)	
Inactive	72 (47.7)	42 (47.7)	30 (47.6)	
BMI (kg/m^2)	29.0 ± 6.2	29.1 ± 6.3	29.1 ± 5.7	0.934
Waist circumference (cm)	95.4 ± 14.5	95.5 ± 14.6	96.0 ± 14.2	0.740
Blood pressure (mmHg)				
Systolic blood pressure	142.5 ± 24.2	159.4 ± 15.7	119.0 ± 10.0	**<0.001**
Diastolic blood pressure	98.0 ± 71.5	113.0 ± 9.8	77.1 ± 7.2	**<0.001**
Mean arterial pressure (mmHg)	127.7 ± 32.3	143.9 ± 33.3	105.0 ± 8.0	**<0.001**

Note: Bold values are measures of significance.
Abbreviation: BMI, body mass index; HTN, hypertension.
*$p < 0.050$ was considered as statistically significant.

triangulated the association between NiDRS and MAP risk diet with CVD biomarkers using the *mediation* package in R [48], which estimated the indirect (i.e., the effect of NiDRS on MAP through a biomarker), direct (i.e., the effect of NiDRS on MAP independent of the biomarker) and total effects (i.e., the sum of the indirect and direct pathways).

RESULTS

Participant characteristics

Exceeding recruitment targets of 150 participants, 165 consenting adults (mean age = 44.4 ± 11.1 years) were enrolled in the study (Figure 1). Of these, 151 (92%) completed the study protocol. As expected, the hypertensive group had a significantly higher systolic, diastolic and MAP compared to the non-hypertensive group (Table 1). A similar number of men and women were recruited, but males comprised a larger proportion of the hypertensive group (59.1%) compared to the non-hypertensive group (36.5%). No significant differences in age, BMI, waist circumference, physical activity, employment, education or marital status were observed between the hypertensive and non-hypertensive groups (Table 1).

Food intake assessment

The mean daily intakes (intake/day) of the 23 food groups within the NiDST are shown in Table S2. Interestingly, the mean intake of 12 food groups commonly considered 'healthy food groups' or 'non-atherogenic food groups' were similar between hypertensive and non-hypertensive participants ($p > 0.05$), but the mean intake of 11 food groups considered 'unhealthy food groups' was significantly greater in quantity by individuals in the hypertensive group ($p < 0.05$) (Table S2 and Figure 2). The average intake of all unhealthy food groups ($n = 11$) among hypertensive groups (0.59 intakes/day) is significantly higher compared to non-hypertensive adults (0.41 intakes/day) ($p = 0.002$) (Table S3).

These 11 unhealthy food groups included red meat, eggs, processed meat, fried and fast foods, soup and stews, desserts and sweets, soft drinks, alcoholic drinks and salt/seasonings. Notably, the food groups included and their weights, which were retained for the development of the NiDRS, differ from the foods and their weights considered by INTERHEART (Table 2, Table S4, and Figure 3). In the NiDRS, level of frequency intake for each food is assigned a weighted score. All questions are answered and summed to calculate the total NiDRS. The minimum score of the NiDRS is 0, and the maximum score is 30.

Validation of the NiDRS

The NiDRS was calculated for all individuals in the validation data set ($n = 30$). The mean NiDRS in the validation

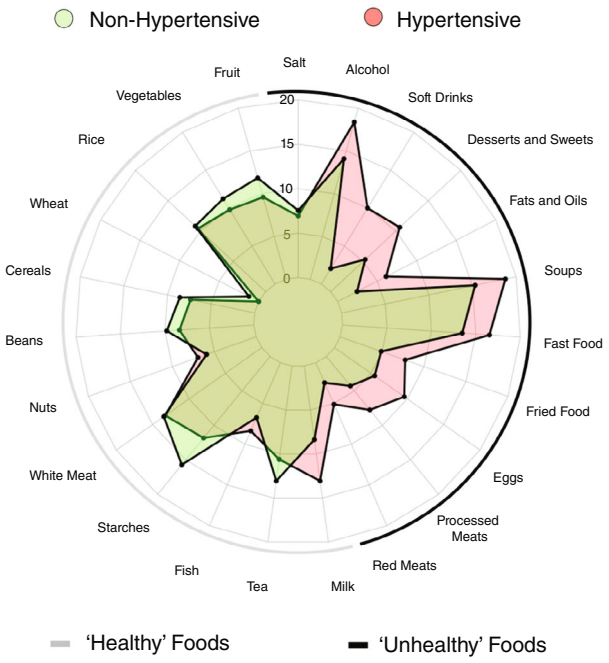

FIGURE 2 Food group intake among adults with and without hypertension in Nigeria. Radar plot showcasing the skewed dietary intake patterns of hypertensive individuals (red) towards foods commonly considered unhealthy (black), compared to non-hypertensive (green) individuals with a more balanced diet of healthy (white) and unhealthy (black) foods.

dataset was 12.4 ± 4.1 (min = 6.6, max = 26.3), with higher scores observed for individuals with hypertension (14.6 ± 5.0) than non-hypertensive group (10.7 ± 2.4). We also report a significant association between the NiDRS and hypertension (odds ratio: 2.04, 95% confidence interval [CI]: 1.16, 3.58, $p = 0.013$) (Table 3), with individuals in the highest NiDRS category at >18-fold increased odds of hypertension, compared to the lowest category (Table 3) and increased probability of hypertension with increased NiDRS (Figure 4).

The assessment of NiDRS calibration (the Hosmer-Lemeshow test) suggests satisfactory model fit ($\chi^2 = 6.9$, $p = 0.544$) and risk category model ($\chi^2 = 5.1$, $p = 0.743$) and good calibration with a Brier score of 0.1 (Table 3). The ROC *c*-statistic reported an area under the curve (AUC) of 92% (95% CI: 80%, 100%) (Table 3 and Figure 4), with maximum accuracy (90%) and precision (92%) when NiDRS score cut-off was set to 11.3. Additionally, as seen in Figure 5, the predictive model provides the greatest net benefits of identifying individuals with hypertension for the threshold probability ranging from 2% to 60% compared to the other strategies (treat all and treat none).

Mediation effect of biomarkers

With a validated NiDRS, the association between diet and hypertension was investigated more closely in the full

TABLE 2 Association between 23 food groups and hypertension in the NiDRS derivative data set.

Food items/groups (intake/day)	β (SE)	OR (95% CI)	*p-value	Weight
Healthy (non-atherogenic) food groups				
Fruits	−0.8 (0.8)	0.5 (0.1, 2.1)	0.326	−1
Vegetables	−1.0 (0.7)	0.4 (0.1, 1.3)	0.117	−1
Rice and pasta	−0.0 (0.7)	1.0 (0.2, 4.0)	0.961	0
Wheat products	0.0 (0.5)	1.0 (0.4, 2.8)	0.979	0
Fibre-rich cereals	−2.3 (1.9)	0.1 (0.0, 3.9)	0.217	−2
Beans and lentils	−0.9 (0.6)	0.4 (0.1, 1.3)	0.134	−1
Nuts and seeds	−1.0 (0.6)	0.4 (0.1, 1.3)	0.116	−1
Tea and coffee	0.6 (0.6)	1.8 (0.6, 5.6)	0.327	1
Dairy (milk)	−0.1 (0.2)	0.9 (0.7, 1.3)	0.643	0
Starchy tubers	−0.2 (0.5)	0.8 (0.3, 2.2)	0.701	0
Fish and seafoods	−0.7 (0.5)	0.5 (0.2, 1.2)	0.128	−1
White (lean) meat	1.1 (0.8)	2.9 (0.7, 12.7)	0.156	1
Unhealthy (atherogenic) food groups				
Eggs and egg products	2.6 (0.9)	12.9 (2.3, 71.6)	0.004	3
Red meat	2.5 (0.8)	12.2 (2.7, 54.9)	0.001	3
Processed meat	3.1 (1.1)	22.8 (2.9, 177.0)	0.003	3
Fried foods	3.7 (1.0)	41.0 (6.2, 273.8)	0.0001	4
Fast foods	1.8 (0.7)	6.0 (1.6, 21.8)	0.007	2
Soups and stew	1.4 (0.7)	4.1 (1.0, 15.8)	0.042	1
Fats and oils	1.8 (0.7)	6.0 (1.7, 21.8)	0.007	2
Desserts and sweets	2.5 (1.0)	12.7 (1.9, 86.5)	0.009	3
Soft drinks	2.9 (0.8)	17.2 (3.9, 76.4)	0.0002	3
Alcoholic drinks	3.4 (0.9)	30.1 (5.1, 178.6)	0.0002	3
Salt and seasonings	3.3 (0.9)	26.5 (4.7, 150.6)	0.0002	3

Note: Multivariable logistic regression models (adjusted for Age, BMI, physical activity levels and sex) in the derivation data set. Weight represents the value of the beta-coefficient approximated to the nearest integer.
Abbreviations: CL, confidence interval; OR, odds ratio; SE, standard error; β, beta-coefficient.
*$p < 0.050$ was considered as statistically significant.

cohort, where blood samples were collected from 94 eligible consenting adults to analyse blood lipids, electrolytes and biomarkers of inflammation (Table 4). As expected, the atherogenic indices, including the atherogenic index of plasma (AIP), atherogenic coefficient (AC), Castelli risk index-I (CRI-I), Castelli risk ratio (CRR) and triglyceride to high-density lipoprotein cholesterol ratio (THDL), were significantly higher ($p < 0.001$) in hypertensive participants compared to then non-hypertensive participants. This was largely driven by significant differences in blood lipids between the groups: TC, TG, LDL-C and VLDL-C were significantly higher ($p < 0.001$) in the hypertensive participants compared to non-hypertensive participants (Table 4). Inflammatory marker, CRP and homocysteine levels were also significantly higher in the hypertensive group ($p < 0.001$) (Table 4). Renal function parameters such as creatinine, urea and serum electrolytes, including sodium, potassium, chloride, bicarbonate and calcium, did not demonstrate any significant patterns, suggesting that both hypertensive and non-hypertensive individuals do not have renal compromise, except for magnesium ($p = 0.009$) (Table 4).

We next examined the association between these biomarkers (mediators) and MAP and NiDRS. The results demonstrated that TC, TG, LDL-C, VLDL-C, CRP, HCY and magnesium have significant positive associations with both MAP and NiDRS (Tables S5 and S6). The mediating effect of these significant biomarkers, such as blood lipids (TC, TG, LDL-C, VLDL-C), inflammatory markers (CRP and HCY) and serum electrolytes (magnesium), on the relationship between the NiDRS and MAP (Figure 6) was evaluated. The result indicated that TC, TG, LDL-C, VLDL-C, CRP and homocysteine significantly mediated the effects (indirect effect) of NiDRS on MAP in a positive direction ($p < 0.05$) (Table 5 and Table S7). Additionally, the proportion mediated by the biomarkers TC, TG, LDL-C, CRP and homocysteine were 50%, 47%, 49%, 68% and 71%, respectively (Table 5 and Table S7). These results suggest that the effect of an unhealthy diet on elevated blood pressure is partly driven by its effect on blood lipids and inflammation biomarkers (17%–71%) and less so via its effect (<7%) on serum magnesium levels.

FIGURE 3 A comparison of foods and their weights in the NiDRS and INTERHEART score. The Nigerian dietary risk score (NiDRS) considered 11 food groups (light grey), which are all positively associated with hypertension, while INTERHEART considers five primary food groups (black), which include negatively and positively associated foods.

TABLE 3 Internal validation of the Nigerian dietary risk score (NiDRS).

Characteristics	Validation dataset ($n = 30$)
NiDRS	
Sex	
Male, *n* (%)	13 (43.3)
Female, *n* (%)	17 (56.7)
Age (years), mean (SD)	48.1 (10.8)
Hypertension diagnosis	
Hypertensive, *n* (%)	13 (43.3)
Non-hypertensive, *n* (%)	17 (56.7)
Mean risk score	12.4 ± 4.1 (min = 6.6, max = 26.3), $p = 0.021$
Hypertensive	14.6 ± 5.0
Non-hypertensive	10.7 ± 2.4
Measures of validation (continuous risk score)	
Odds ratio (95% CI)	2.0 (1.2, 3.6), $p = 0.013$
ROC *c*-statistic (95% CI) (%)	92 (80, 100)
Brier score	0.10
Hosmer-Lemeshow test	$\chi^2 = 2.8$, $p = 0.945$
Accuracy (%)	90.0
Precision (%)	92.0
Sensitivity (TPF) (%)	85.0
Specificity (%)	94.0
1-specificity (FPF) (%)	6.0
NiDRS risk category	
High (score ≤11.3)	9.5 ± 1.4 (min = 6.6, max = 11.3)
Low (score >11.3)	15.3 ± 3.9 (min = 11.4, max = 26.3)
Measures of validation (binary risk category)	
OR (95% CI) (ref: low)	18.3 (1.3, 251.2), $p = 0.030$
ROC *c*-statistic (95% CI) (%)	87 (75, 100)
Brier score	0.15
Hosmer-Lemeshow test	$\chi^2 = 5.1$, $p = 0.743$
Accuracy (%)	76.7
Precision (%)	75.0
Sensitivity (%)	69.2
Specificity (%)	82.4
1-specificity (%)	17.6

DISCUSSION

In this study, we identified the 11 key unhealthy food groups that significantly increased the risk of hypertension in Nigeria and then calculated and validated the NiDRS for hypertension. We also investigated the NiDRS alongside a panel of clinical predictors and markers of hypertension to report on its biological pathway to mediate hypertension. The NiDRS demonstrated a remarkable ability to stratify participants by low- versus high-hypertension risk in Nigeria.

Our study confirmed that consumption of high amounts of unhealthy food groups, including red meat, processed meat, eggs, fried foods, fast foods, fats and oils, desserts and sweets, soft drinks, alcoholic drinks and salt and seasoning, is indicative of an unhealthy dietary pattern in Nigeria. These unhealthy food groups were associated with an increased risk of hypertension and were therefore included in the final food group list to create the NiDRS. Globally, these unhealthy food groups are commonly associated with an increased risk of cardiovascular disease and are frequently included in the development of dietary risk score tools for hypertension or cardiovascular disease in Western countries [49–53]. The limited ability of healthier foods to discriminate between low- and high-risk individuals has been reported previously in the United States and Europe [54]. Our findings suggest that a disproportionate

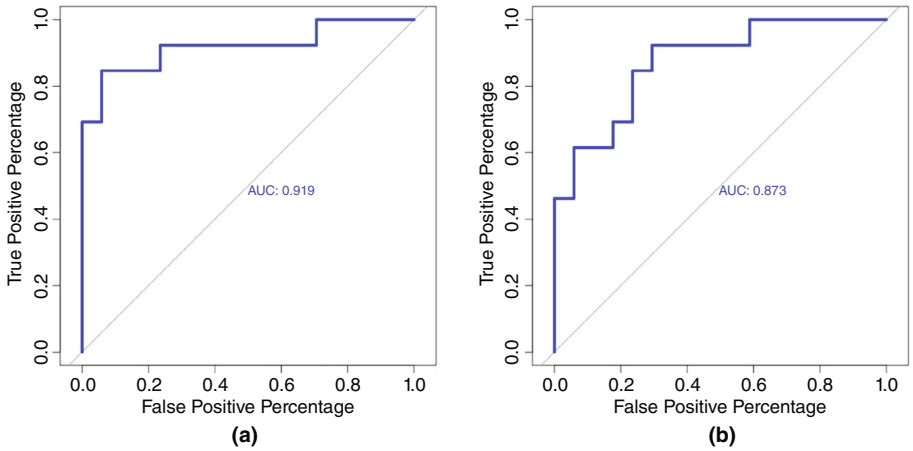

FIGURE 4 Receiver-operating characteristic curves for the Nigerian dietary risk score (NiDRS) in the validation data set. (a) risk score; (b) risk score category; AUC, area under curve.

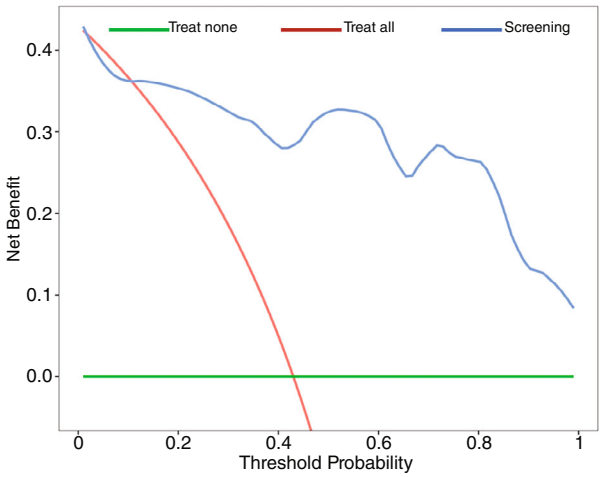

FIGURE 5 Decision curve analysis of NiDRS for prediction of hypertension risk. Green line represents the strategy of no dietary screening with the Nigerian diet risk score (NiDRS). Red line represents the strategy of screening all patients with NiDRS. Blue line represents the strategy of using the NiDRS multivariable prediction model.

intake of food groups from animal-sourced, processed/convenience foods and alcohol are the key dietary drivers of hypertension risk in Nigeria [10].

These unhealthy food groups align with those identified in the INTERHEART study, which also highlights the consumption of salty foods, deep-fried foods and high-frequency meat consumption as key contributors to cardiovascular disease risk. However, our study identifies the contribution of specific food groups that are prevalent in Nigerian diets. For example, while salty foods, deep fried (including snacks and fast foods) and meat are commonly considered by the NiDRS and INTERHEART, the NiDRS considers the use of 'fats and oils' (including palm oil, a common component in Nigerian cooking) and consumption of traditional 'soups and stews' (a calorie-dense Nigerian cuisine with protein and sodium-rich condiments) which are not directly considered by INTERHEART as a key factor that contributes to HT. In summary, these distinctions support the call and need for a culturally tailored screening tool for HT in Nigeria.

The NiDRS demonstrated a robust internal validity, with strong discrimination and calibration in a validation sample. Each one-point increment in NiDRS (on a scale of 0 to 30) was significantly associated with two-times higher odds of hypertension, while individuals scoring >11.3 (the highest risk category of the NiDRS) exhibited significantly higher odds of hypertension, that is, an increased odds of 18.3, compared to those with a NiDRS score in the lowest risk category (score ≤11.3) (Table 3). These findings are consistent with outcomes of risk scores, which either agree with or are better observed in previous studies [39, 55, 56], and the validity of both the continuous and binary risk score supports its use as a dietary screening tool [57]. The result suggests that the NiDRS can be an effective dietary screening tool to assess individuals with a risk of hypertension in Nigeria.

Additionally, for a predictive score to have a meaningful impact on disease prediction, the AUC, the true-positive fraction (sensitivity), and the false-positive fraction (1-specificity) should be close to their ideal values of 1 and 0, respectively [58, 59] with a positive net benefit [45, 60]. Our findings demonstrated a notable strength of association, indicating the risk score's ability to discriminate individuals with or without hypertension, as indicated by the ROC-AUC ranging from 87% to 92%. Our predictive models demonstrate strong discriminatory power with sensitivity ranging from 69% to 85% and a false-positive fraction (1-specificity) of 6% to 18% for the continuous and binary risk score and potential benefit over a wide range of thresholds probability of dietary screening of individuals at risk of hypertension. This aligns with or exceeds the results of previous work, where the performance of the INTERHEART modifiable risk score was with AUC ≥69% [39], the Framingham Heart Study with AUC between 76% and 79% [61] and the SCORE project with AUC ≥71% [62].

TABLE 4 Biomarkers characteristics of a subset of the study cohort ($n = 94$).

Biomarkers/mediators	Overall ($n = 94$)	Hypertension ($n = 59$)	Non-hypertension ($n = 35$)	*p-value
Fasting lipid profile				
TC (mmol/L)	3.7 ± 1.3	4.2 ± 1.3	2.8 ± 0.6	<0.001
TG (mmol/L)	1.5 ± 0.3	1.7 ± 0.3	1.3 ± 0.2	<0.001
HDL-C (mmol/L)	1.4 ± 0.2	1.5 ± 0.2	1.5 ± 0.2	0.823
LDL-C (mmol/L)	3.2 ± 1.6	3.7 ± 1.5	2.2 ± 1.1	<0.001
VLDL-C (mmol/L)	0.7 ± 0.2	0.7 ± 0.1	0.6 ± 0.1	<0.001
Atherogenic indices				
AIP	0.0 ± 0.1	0.1 ± 01	−0.1 ± 0.1	<0.001
CRI-I	2.6 ± 1.0	2.9 ± 1.0	2.0 ± 0.5	<0.001
CRI-II	2.2 ± 1.2	2.6 ± 1.2	1.5 ± 0.6	<0.001
NHDL-C	2.3 ± 1.3	2.7 ± 1.3	1.4 ± 0.7	<0.001
THDL-C	1.1 ± 0.3	1.2 ± 0.2	0.9 ± 0.1	<0.001
C-reactive protein (mg/dL)	4.4 ± 3.1	6.3 ± 2.3	1.2 ± 0.5	<0.001
Homocysteine (μmol/L)	14.5 ± 5.5	17.8 ± 4.0	9.0 ± 2.2	<0.001
Serum electrolytes				
Sodium (mmol/L)	137.8 ± 15.1	139.1 ± 15.3	135.5 ± 14.8	0.272
Potassium (mmol/L)	3.7 ± 1.0	3.9 ± 1.0	3.5 ± 1.1	0.057
Chloride (mmol/L)	78.4 ± 9.8	78.5 ± 9.8	78.2 ± 9.8	0.890
Bicarbonate (mmol/L)	24.1 ± 3.5	25.3 ± 4.0	24.8 ± 2.6	0.481
Calcium (mmol/L)	2.5 ± 0.4	2.5 ± 0.3	2.6 ± 0.5	0.313
Magnesium (mmol/L)	2.1 ± 0.2	2.1 ± 0.1	2.0 ± 0.2	0.009
Renal function test				
Creatinine (μmol/L)	80.4 ± 17.9	82.5 ± 17.4	76.7 ± 18.5	0.138
Urea (mmol/L)	3.2 ± 0.9	3.3 ± 0.9	3.0 ± 0.8	0.124

Note: Results are presented as mean ± SD.
Abbreviations: AIP, Atherogenic Index of Plasma; CRI-I, Castelli Risk Index I; CRI-II, Castelli Risk Index II; NHDL-C, non-HDL cholesterol; THDL, triglyceride to high-density lipoprotein cholesterol ratio.
*$p < 0.050$ was considered as statistically significant.

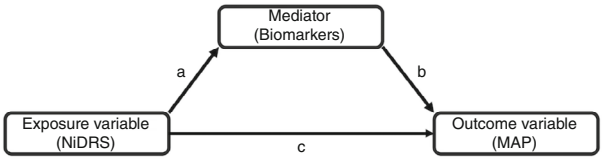

FIGURE 6 Path diagram of the mediation linear regression model. Path a: direct effects of Nigerian diet risk score (NiDRS) on biomarkers; Path b: direct effect of biomarkers on mean arterial pressure (MAP); Path c: direct effects of NiDRS on MAP.

Overall, these results suggest the robustness and effectiveness of the NiDRS for the dietary screening of individuals at risk of hypertension and support the clinical usefulness of the risk score in Nigeria.

Furthermore, our study demonstrated a robust positive association between the NiDRS with biomarkers such as TC, TG, LDL-C and inflammatory markers such as CRP and homocysteine (Hcy). This association suggests that the risk score, reflecting food groups considered 'unhealthy' in the Western dietary pattern, correlates with a higher risk of abnormal blood lipids such as TC, TG and LDL-C and inflammatory biomarkers such as CRP and Hcy [63–69]. Our mediation analysis further demonstrated that TC, TG, LDL-C and inflammatory markers such as CRP and homocysteine significantly mediated the association between NiDRS and MAP. Specifically, these biomarkers showed indirect effects on MAP changes, with proportions of the total effect mediated ranging from 40.25% to 60.20%. These findings confirm a major biological pathway by which diet elicits its effect on hypertension risk and posits lipid and inflammatory markers as key targets for non-dietary strategies where diet alone is inadequate.

Strengths and limitations of the NiDRS

The NiDRS has several strengths. Nonetheless, firstly, it was constructed using a data-driven approach with clinical usefulness at the forefront and adjustment for confounding factors associated with hypertension [22]. Secondly, we validated the NiDRS, in an independent subset of the

TABLE 5 Biomarkers mediated effect of NiDRS on mean arterial pressure.

Mediators	Indirect effect β (95% CI)	Direct effect β (95% CI)	Total effect β (95% CI)	Proportion mediated
Fasting blood lipids				
TC (mmol/L)	0.5 (0.2, 0.9)***	0.5 (−0.1, 1.0)	1.0 (0.4, 1.5)***	0.50***
TG (mmol/L)	0.5 (0.2, 0.8)***	0.5 (−0.1, 1.0)	1.0 (0.4, 1.5)***	0.47***
LDL-C (mmol/L)	0.5 (0.1, 0.9)*	0.5 (−0.1, 1.1)	1.0 (0.5, 1.4)***	0.49*
VLDL-C (mmol/L)	0.2 (0.0, 0.4)	0.8 (0.3, 1.3)**	1.0 (0.4, 1.5)***	0.17
Inflammatory biomarkers				
CRP (mg/dL)	0.7 (0.3, 1.0)***	0.3 (−0.2, 0.8)	1.0 (0.4, 1.5)***	0.68***
HCY (μmol/L)	0.7 (0.4, 1.1)***	0.3 (−0.2, 0.7)	1.0 (0.4, 1.5)***	0.71***
Serum electrolytes				
Magnesium(mmol/L)	0.07 (−0.0, 0.2)	0.9 (0.4, 1.4)***	1.0 (0.4, 1.4)***	0.06

Abbreviations: CRP, C-reactive protein; HCY, homocysteine; LDL-C, low-density lipoprotein cholesterol; NiDRS, Nigeria diet risk score; SE, standard error; TC, total cholesterol; TG, triglyceride; VLDL-C, very low-density lipoprotein cholesterol; *β*, beta-coefficient.
*$p < 0.05$; **$p < 0.01$; ***$p < 0.001$ was considered as statistically significant.

participants. Thirdly, the NiDRS synthesises patient-level dietary risk scores and classifies individuals into binary risk categories, which can help patients better understand how their personal dietary habits and choices influence their risk of cardiovascular disease and hypertension [39, 70]. Finally, the mediation analysis and the association between NiDRS and clinical CVD outcomes further support the NiDRS by providing biological plausibility, clinical relevance and overall reliability, reinforcing its usefulness as a dietary screening tool for hypertension [71, 72]. However, there are limitations to the NiDRS that must be acknowledged. Although the tool was validated within the study cohort, it needs further external validation to ensure its robustness across different populations and settings.

Study limitations

The study also has some limitations. The dietary intake data collected were self-reported, which can be subject to recall bias. Additionally, the study used a case–control design rather than a prospective cohort, limiting the ability to infer causality. Lastly, while we validated the NiDRS in an independent subset of participants, further validation in external populations is needed to assess its generalisability and accuracy [73]. This will be a priority we aim to address in the next phase of our research.

Clinical and public health relevance

The NiDRS for hypertension offers healthcare professionals and researchers a culturally appropriate and evidence-based tool to evaluate individuals at risk of hypertension and deliver personalised dietary counselling and motivational support. By leveraging the NiDRS, clinicians can proactively intervene by offering dietary guidance and recommendations unique to each patient's dietary needs and individual circumstances. This approach fosters patient engagement and understanding of their dietary risk level and serves as a motivating factor as they observe their risk score decrease with improvements in their dietary behaviours. This approach has been recommended by the Nigerian National Strategic Plan of Action for Nutrition [74], the American Heart Association [75, 76] and the European Society of Cardiology guidelines [77]. The widespread adoption of the NiDRS may contribute to reducing the overall prevalence of hypertension in Nigeria and other West African nations, thereby alleviating the burden on healthcare systems and improving population-level health outcomes [74].

CONCLUSION

We have developed and validated a diet risk score for hypertension risk (NiDRS) tool designed to assess hypertension risk in Nigerian clinics. The NiDRS is a valuable tool to (i) provide clinicians, patients and researchers with a practical means to identify individuals at high risk of hypertension and (ii) facilitate early intervention strategies, which will mitigate and optimise cardiovascular health management in Nigeria. As such, it represents a significant advancement in the prevention and management efforts of hypertension in Nigeria, offering a promising tool to combat the rising prevalence of hypertension and its associated complications.

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CONFLICT OF INTEREST STATEMENT

The authors have no conflicts of interest to disclose.

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

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